Document Title: The Acquisition of Sebaceous Fingerprint Topology Using Columnar Thin Films (CTF) on Forensically Relevant Substrates

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Abstract

The purpose of this basic-science research project was to expand on successfully completed proof-of-concept experiments by, first, determining the scientific basis of and the application of columnar thin films (CTFs) to capture friction ridge detail found in latent fingerprints on nonporous forensically relevant textured substrates and then to compare CTF development of fingerprints with commonly employed fingerprint development techniques used for that purpose.

Latent, sebaceous fingerprints were deposited on forensically relevant substrates, and then CTFs were deposited on these latent fingerprints using the conformal-evaporated-film-by-rotation (CEFR) technique. The specific objective of this basic research was to investigate the fundamental scientific and physical characteristics required to use CTFs to capture and visualize latent, sebaceous fingerprints by identifying the necessary CTF materials and deposition conditions required to develop fingerprints on selected forensically relevant substrates. Secondarily, the research design included a comparison of CTF-developed prints with traditionally developed fingerprints on the same substrates, with minimum variability of factors that could be controlled.

In order to make comparisons between CTF-developed and traditionally developed prints, we needed an objective method for assessing the quality of developed prints. Although there are references available in the literature for determining quality (1), none seemed suitable for our purposes because they often employ a subjective evaluation of some aspect of the developed fingerprint. In order to completely evaluate developed fingerprints objectively, we devised a system requiring the successive use of three separate, commercially available computer programs that collectively transform a photograph of a fingerprint into a multicolor-coded quality map, change the colors into a red-green-blue (RGB) spectrum, count the number of those pixels whose color corresponds to regions of definitive identifiable minutiae, and calculate the percentage of the fingerprint area which has definitive identifiable minutiae. The initial manipulations in the system are implemented on the FBI's universal latent workstation (ULW). The devised system gave us the ability to completely evaluate fingerprints objectively. The system is easy to use and was effective for our purposes.

The research was divided into two phases: I and II. In Phase I, we determined the scientific parameters related to CTF development of fingerprint friction ridge detail on forensically relevant substrates. This work entailed optimizing the deposition pressure, average vapor flux angle, deposition rate, substrate rotation rate, and CTF thickness on glass slides. Cross sections of various thicknesses were taken via scanning electron microscope (SEM) to show that CTF morphology does not vary greatly with thickness. We found a cross section of a coated ridge that clearly demonstrated the conformal nature of CTF coatings on latent fingerprints. Additionally, cross sectional SEM images of several different CTFs taken at various viewing angles were used to calibrate a quartz crystal monitor (QCM). Depositions of chalcogenide-glass CTFs were also made with the modified-CEFR method for comparison.

In Phase II, we developed latent, sebaceous fingerprints on various forensically relevant nonporous substrates that are difficult or not ideally suited to traditional fingerprint development techniques. For each substrate, we developed fingerprints using (i) CTF capture of friction ridge detail and (ii) a traditional technique typically employed for that substrate and which gave the best results in our laboratory. For some substrates, CTF development was superior. For other substrates, the traditional technique was superior. For still other substrates, the two techniques showed equal capability of developing fingerprints.

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Executive Summary

Purpose

The purpose of this basic-science research project was to expand on successfully completed proof-of-concept experiments by: first, determining the scientific basis of and the deposition of columnar thin films (CTFs) to capture friction ridge detail found on forensically relevant textured substrates, and, second, to compare CTF development of fingerprints with the results of commonly employed fingerprint development techniques used. The technique used to capture friction ridge detail is the conformal-evaporated-film-by-rotation (CEFR) technique, which is a variant of the oblique angle vapor deposition technique that has been used for about 150 years to deposit optical thin films. Used to fabricate high-fidelity replicas of biological templates such as the eyes of flies and the wings of butterflies (3,4), the CEFR technique is particularly suited to fingerprint development because it can deposit thin films at micro- and nano-scales over planar and curved substrates. Importantly, this technique is based on thermal evaporation combined with simultaneous substrate tilting (for obliquely directed vapor flux) and rapid rotation, which causes the columns of nanoscale diameters to grow upright (5,6), making this technique highly suitable for the solid-state acquisition of fingerprint topology. The CEFR technique was used for all of the CTF fingerprint development in this research project.

Research design

This research was conducted in two phases: I and II. The first phase of the research, Phase I, employed the CEFR technique to determine the scientific basis of the CTF capture of latent friction ridge detail. For the initial studies, we deposited chalcogenide glass on sebaceous fingerprints placed on glass microscope slides and then varied the critical parameters of the CEFR technique: deposition pressure, average vapor flux angle, deposition rate, substrate rotation rate, and film thickness. We also used several different evaporant materials.

Research in Phase II involved creating a series of split, sebaceous fingerprints on various nonporous forensically relevant substrates. These fingerprints were developed using various evaporant materials with the CTF development technique and by traditional fingerprint development techniques typically used for that substrate. The specific CTF evaporant material was chosen by experimentally determining the best for that substrate. The traditional development technique was chosen by experimentally identifying the best of those that were tested. After developing the split fingerprints, each split pair was photographed and then analyzed for quality using a quality grading system. Initially, a subjective grading system was used, but it was later replaced by an objective grading system devised by us. In order to limit variability, the fingerprints of only one donor were used in all comparative studies.

Findings and conclusions

The results of the Phase I research are shown in Table 2 for the critical CTF deposition parameters for developing sebaceous fingerprints: a base pressure of 10^{-4} Torr is necessary to capture friction ridge detail, significantly less than what was initially predicted (2), an average vapor flux angle of 20º, a CTF deposition rate of 1 nm s^{-1}, and a substrate rotation rate of 180 rpm. The optimum CTF thickness did depend on the evaporant material. For instance, 50-nm-thick CTFs of gold provided optimal contrast on some substrates, whereas the optimal thickness of a CTF of chalcogenide glass on other substrates turned out to be 20 times higher. For all other combinations of the evaporant material and substrate tested, the optimal CTF thickness was found to lie between 50 and 1000 nm, both inclusive.

The results of the optimization study are shown in Figs. 3A-E. The results clearly demonstrate the development of friction ridge detail to the pore level (Figs. 3B and C). Furthermore, the CTF forms on the ridges of the fingerprints (Fig. 3E). This is in contrast with another low-pressure deposition technique, Vacuum Metal Deposition (VMD), in which gold is first deposited, the gold typically penetrating the fingerprint ridge, followed by a second metal, typically zinc. In VMD, neither metal is deposited *on* the fingerprint ridges. Although a head-to-head comparison between CTF development and VMD development was not envisaged for this research project, a preliminary comparative study was undertaken towards the end of the project period.

Phase II of the research required the deposition of split sebaceous fingerprints on forensically relevant substrates. The following procedures were followed for collecting sebaceous secretions. The fingertip was cleansed with ethanol, allowed to dry, and then swiped across the forehead, nose, and chin of the donor 20 times. Two fingerprints were placed on a glass slide to remove excess sebaceous secretions, and then two fingerprints were placed onto the substrate of interest for analysis. This procedure was repeated until the desired number of samples was reached. We used one fingerprint donor, unless otherwise noted, in order to minimize variability and maximize consistency among experiments. For each experiment, four duplicate fingerprints were collected. Fingerprints were aged 24 h prior to development. In subsequent experiments where sensitivity of the CTF technique was studied, depletion experiments were necessary. We found interference from eccrine secretions, and that forced us to redesign the fingerprint collection method. The depletion study was taken to the 300th fingerprint – but, as the sebaceous secretions were depleting as each fingerprint was placed on a substrate, eccrine secretions caused the fingerprints not to be depleted. We determined that thin plastic wrapped around the finger allowed us to obtain fingerprints without eccrine secretion interference. For those sensitivity studies, sebaceous secretions were collected as described except that a thin plastic wrap was wrapped around the finger, allowing us to collect every 2nd fingerprint until the 12th fingerprint.

Split, sebaceous fingerprints were deposited on the nonporous substrates shown in Table 1. The general category of substrates included: brass (Alloy 260), stainless steel (420 grade), adhesive tapes – smooth and sticky sides – (Scotch Duct, Gloss Finish Scotch Multitask, Scotch Masking and Gorilla), hard plastics (ABS, nylon), soft plastics (black garbage bags, white grocery bags, clear sandwich bags), stained and sealed woods (cherry, walnut). Other forensically relevant substrates were also chosen because of their problematic development using traditional fingerprint development techniques. These included partial bloody fingerprints on stainless steel and other substrates. We also collected fingerprints on 9 mm Luger brass cartridge casings discharged from a Ruger P95 pistol

Each split fingerprint deposited on a nonporous substrate was developed using the optimized CTF deposition procedure. Various evaporant materials were used in order to determine the evaporant material most appropriate for a particular substrate. This was followed by development using a traditional technique typically employed for that substrate; see Table 1. This information is presented in Table 3. For example, for latent fingerprints on brass, chalcogenide glass (1000 nm thick CTF) was the best CTF evaporant material, whereas black powder and cyanoacrylate fuming gave the best results of the all the traditional techniques selected. For latent fingerprints on stainless steel, chalcogenide glass and nickel were the best evaporant materials, whereas cyanoacrylate fuming and cyanoblue were the best traditional techniques. For latent fingerprints on stained and sealed walnut and cherry, ABS (black and white), and nylon, the fluorescent material Alq_3 afforded the best CTF development. Dusting with white magnetic powder and dusting with black magnetic powder were the best traditional techniques for walnut and cherry wood, respectively. Dusting with red fluorescent powder gave the best results among the selected traditional technique for developing fingerprints on black ABS, white nylon, and black nylon, while dusting with black magnetic powder performed the best on white ABS. Soft plastic (black garbage bag) responded best to nickel as the evaporant material for CTF development and to dusting with red fluorescent powder.

Superglue fuming (heat and humidity variation) is a traditional development technique we used to develop fingerprints on several of the substrates studied (Table 1). In fact, it was the traditional technique of choice for stainless steel (Table 3). In Phase II, we found that a combination of cyanoacrylate (superglue) fuming and CTF deposition gave superior results for discharged cartridge casings. The reason this hybrid technique works so well is that the cyanoacrylate polymer that layers on top of the friction ridge detail after fuming enhances the topology of the fingerprint. Since the CTF technique responds well to topological differences between the friction ridge detail and the underlying substrate, the enhanced friction ridge structure resulting from cyanoacrylate fuming makes the hybrid technique (cyanoacrylate fuming followed by CTF development) a potentially valuable fingerprint development technique that warrants further study for discharged cartridge casings as well as for other substrates.

Data analysis

After each development of split pairs of fingerprints using the CTF technique and the best traditional technique studied, the results were photographed and the quality of each assessed. We found that it was impossible to assess the true quality of the developed prints using published procedures (1) because they involve an element of subjectivity. We wanted a system that evaluates quality completely objectively. The system we designed uses three sequential computer programs that assess the relative (percent) of the developed fingerprint having definitive minutiae (Section II.8). Using this objective grading system, we were able to objectively assess the quality of each developed fingerprint and identify which development, CTF or traditional, gives the better result.

Implications for policy and practice

This research demonstrated that CTF development of fingerprints on nonporous forensically relevant substrates that are not ideal for traditional fingerprint techniques gives superior or equal results for all of the substrates studied except for masking tape, stainless steel, white ABS, and black nylon. Although the CTF development of sebaceous fingerprints is applicable for a wide range of substrate types, it appears to be particularly suitable for partial bloody fingerprints, for which traditional techniques are inefficacious. Partial bloody fingerprints are problematic with respect to the two different aspects of the print that must be developed: the latent (sebaceous) and patent (bloody) parts. This research showed that just one CTF deposition was able to develop both parts of the fingerprint simultaneously. The CTF technique also holds promise for developing fingerprints on discharged cartridge casings using Alq_3, a fluorescent material, as the evaporant material.

Other low-pressure techniques are employed for fingerprint development: vacuum superglue fuming and VMD. The latter is similar in concept to CTF techniques but substantially different. VMD was not one of the traditional development techniques studied as part of this research. A comprehensive comparison of the two techniques should be undertaken in future research.

This research employed ideal, laboratory prepared, sebaceous fingerprints as a first approach. Also, fingerprints from a single donor were almost exclusively used in order to best ascertain how well the CTF technique compares with traditional development techniques. This, however, is not reality because latent fingerprints at crimes scenes have different ratios of eccrine and sebaceous secretions (we specifically chose to study sebaceous-only fingerprints). Additionally, these fingerprints can be aged longer than the 24-h period we used for our research and are also exposed to varying environmental insults (heat, humidity, pollution, etc.).

Another important finding of this research was that the base pressure of the low-pressure chamber used in our proof-of-concept studies (2) was significantly lower than the Phase I optimization studies of this project demonstrated was necessary for sebaceous fingerprint development. This is important because it means that the low-pressure system required for CTF development is not as costly as originally believed. It also paves the way for a field-deployable CTF development system.

Main Body

I. Introduction

I.1. Statement of the problem

While most on-scene and in-laboratory fingerprint development applications employ either physical or chemical techniques, none have explicitly explored the texture of the fingerprint topology as a basis for development. As fingerprints age or are exposed to environmental stress, the chemical and some of the physical characteristics becomes progressively more difficult to develop. For instance, drying of the friction ridge detail, in essence the fingerprint residue, hinders development. While it is as yet completely unknown for all possible latent fingerprint environments, it is expected that – even though the chemical and physical characteristics of fingerprint residue may become progressively more difficult for development – sufficient texture or topology of the fingerprint may remain that is amenable to textural analysis.

We must employ a technology that can develop latent fingerprints based on the topological characteristics of the fingerprint residue in those circumstances where commonly employed techniques might either not work or be ideal. Since a latent fingerprint is deposited as a residue, it has texture – ridges, pores and grooves – different from the texture of the substrate upon which it is deposited. This is especially true for nonporous substrates. The premise of this research project was that latent fingerprints are amenable to Columnar Thin Film (CTF) acquisition technology.

The purpose of this project was to expand on successfully completed proof-of-concept experiments (2) by: first, determining the scientific basis of and the application of CTFs to capture – entomb – the friction ridge detail found on forensically relevant textured substrates and, second, to compare CTF development of fingerprints with commonly employed fingerprint development techniques. Our proof-of-concept experiments had shown us that CTFs can copy the topography of fingerprint residue on selected non-porous substrates (2).

Although the deposition of CTFs is a well-understood technology (7,8), it has never been applied systematically to fingerprint development. In light of the recommendations of the National Research Council concerning forensic testing (9), determination of the underlying scientific basis of new technology and its limitations, such as CTF fingerprint development, is critical. The objectives and goals of this research project were to investigate the fundamental scientific and physical characteristics required for CTF capture of latent fingerprint topology by identifying the necessary CTF evaporant materials and deposition conditions required to develop fingerprints on selected nonporous forensically relevant substrates and then to compare CTF developed fingerprints with traditionally developed fingerprints on the same substrates. In order to meet these goals, we conducted the research in two overlapping phases covering two years.

I.2. Review of literature

Fingerprint uniqueness continually attracts researchers to search to improve locating, visualizing and lifting fingerprints at scenes of crimes and visualizing and enhancing them in the laboratory. Each fingerprint found at a scene is endowed with a complex and unique blend of chemical and physical characteristics, the constituents being a varying composite of secretions of the major secretory glands (10). The specific composition of fingerprint residue varies depending on the relative contributions of each gland and the specific chemistry of each person (10). Fingerprint residue is typically an emulsion: a mixture of water, eccrine secretions (salts, proteins, small organic molecules, etc.), sebaceous secretions (mono, di and triglycerides; sterols; wax esters; fatty acids, etc.), and other contaminants (blood, cosmetics, etc.).

Many substrates, on which evidence is found, can be too large to fit into a low-pressure chamber required for CTF deposition. Still, many forensically relevant substrates can be relatively small and will fit into that chamber. Latent fingerprints, even on those substrates for which commonly used development techniques are not ideal, should have topographic detail that should be amenable to CTF development and subsequent analysis. The substrates and fingerprint types that are the focus of this research project are described next.

I.2.1. Nonporous substrates: Metals, handles of weapons (plastics & wood), adhesive tapes

Developing a latent fingerprint at the scene or in the laboratory requires an understanding of the substrate on which the fingerprint lies (11-21), and knowledge of the specific physical and chemical techniques applicable to develop the fingerprint on that specific substrate (11,12). For plastics (16,17), tapes (11,12,16,17), and metals in firearms and discharged cartridge casings (11,19-21), no *set* methods exist. Although there may be a logical explanation with respect to why discharged cartridge casings may not have useable latent fingerprints (11), prior to this research they had not been subjected to CTF analysis. This means that there are a variety of techniques used to develop latent fingerprints on these substrates, but there is not one that is universally applicable, individually, to all plastics, all metallic substrates, or all tapes (11,12), both smooth and sticky sides (18). For metals, recent work suggests that print-etching of the metallic substrate can be useful to visualize latent prints (19-21). The etching process creates substrate texture that should be amenable to CTF development and analysis. For plastics, one common development method involves superglue fuming. However, even this method does not work for all plastics, the success depending on the specific fuming method employed (15). A method often seemingly more useful for plastics is VMD (11,16,17). For plastic substrates, the fingerprint residue should have a texture and therefore be amenable to CTF development.

I.2.2. Porous substrates

Standard methods exist for developing latent prints on porous substrates. And while it could be expected that the usual porous substrates would not be successful with CTF development, this is not known. There are porous substrates categorized as *hard*, that is, those into which the sebaceous secretion do not enter rapidly (13). While hard porous substrates may produce CTF-developable fingerprints, porous substrates are not the subject of this research project.

I.2.3. Environmental stress and ageing

Ageing and environmental insults can affect an investigator's ability to develop latent prints (11). Over time, ageing dries the fingerprint residue, which hardens the emulsion making it relatively insensitive to common dusting and superglue fuming techniques (22). Environmental insults also affect the fingerprint's emulsion, which will vary in different regions of the country and at different seasons of the year. Like ageing, dry, hot weather dries the fingerprint residue making it difficult to be analyzed (22). Similarly, cold weather hardens the oils in the fingerprint residue, again making it resistant to traditional development techniques. Certainly, it is possible to reverse the drying effects somewhat, but this requires an extra treatment at the scene, for on-scene development, or in the laboratory (22).

With respect to all latent fingerprint development, an unknown parameter concerns the integrity of the fingerprint residue, whether the damage occurred because of the environment or during deposition of the fingerprint. However, if the fingerprint residue is present and it has texture, regardless of its chemical or physical integrity, it should be amenable to CTF development. Research concerning the ability to effect CTF development on environmentally insulted fingerprints was not the focus of this research project, but the issues involved must be tackled in subsequent research.

I.2.4. Partial bloody prints

Partial bloody prints are commonly found on objects at a crime scene. Although developmental issues for blood enhancement were not addressed in this research project specifically, they can pose potential problems if the print is a partial bloody print, where one part of the fingerprint is latent and the other patent. Certainly, the bloody, patent part is easily enhanced using common protein stains (23). These might also enhance selected areas of the visually latent part if those areas are also bloody, even if the amount of blood present were below the detection limits of the human eye. From the perspective of this research project, both the latent and patent parts of the print should have textural detail amenable to CTF development.

I.2.5. CTF technology

The premise underlying this basic-science research project is that a physical vapor deposition (PVD) method called the conformal-evaporated-film-by-rotation (CEFR) technique is applicable to fingerprint development with the potential to develop latent fingerprints on substrates for which traditional development techniques are either inadequate or not ideal. For this work, the formation of upright columnar thin films (CTF) via the CEFR technique was used to capture fingerprint topology, a technique fundamentally different from other low-pressure fingerprint development techniques such as vacuum superglue fuming (15) and VMD (16,17).

The technique closest to CTF is VMD, wherein gold is first evaporated in a low-pressure chamber to form a thin layer on the exposed substrate, the gold penetrating the fingerprint residue. Next, a layer of zinc or cadmium is deposited in the same manner. This second layer lies atop the gold layer but supposedly does not penetrate the fingerprint emulsion, leaving the fingerprint ridges transparent while the zinc/cadmium background is dark (17). In contrast, the CTF forms a conformal coating on the fingerprint ridge and thus maps the topography of the fingerprint.

CTF technology has been known for over a hundred years (7,24). CTFs of solid materials have been deposited as coatings (7,8,25) for optical, magnetic, electrical, tribological, and other purposes. The CTF coatings are assemblies of parallel, straight columns or nanowires. Typically, a CTF grows on a planar substrate mounted on a platform, the tops of the columns together constituting a surface that is almost planar. When the substrate has a slight undulation, possibly due to a dust particle or a manufacturing defect, that undulation, which is highly undesirable for most practical CTF applications in such fields as optics or microelectronics, is manifested at the top surface (26). Consequently, if a CTF were to be deposited on a fingerprint, the top surface of the CTF would be expected to reproduce the topological details of the fingerprint. The result could then be visualized using traditional optical techniques, ideally obviating the need for subsequent chemical or other physical development methods. Additionally procedures that add texture to the existing latent fingerprint residue – superglue fuming, etc. – would be expected to enhance CTF formation.

The concept behind the proposed solid-state acquisition of fingerprint topology can be explained by comparing it to a child's toy called the Pin Point Impression (27) shown in Fig. 1. This toy is a dense collection of parallel and identical cylindrical pins. When the pins are made to stand erect over a flat surface, the pin heads form collectively a surface that is also flat (Fig. 1, left panel). When the pins stand over an undulating surface, the pin heads also form an undulating surface (Fig.1, right panel), the undulations of the top surface mimicking the undulations of the bottom surface. The smaller the cross-sectional radius of the pins and the larger the number density of pins, the more faithful will be the replication of the topological features of the bottom substrate by the top surface created by the pin heads. If the pins of the toy could be glued together, they would *record* the topological features of the undulating substrate.

The Pin Point Impression toy is analogous to the morphology of CTFs whose growth occurs by thermal evaporation. In early experiments (2), at a pressure of around 1 μTorr, material (chalcogenide glass) in a source boat was electrically heated to evaporate upward toward a fingerprint deposited on various substrates; see Fig. 2. The fingerprints face the source boat allowing the evaporating material to settle thus forming a dense CTF. Typically, isolated nucleation clusters about 1-3 nm in diameter initially form on the substrate, usually without reacting chemically with the fingerprint residue. These clusters evolve into expanding and competing columns as the film thickness increases. This has been reviewed elsewhere (8). Such growth conditions describe most optical thin-film coatings used commercially.

If the circumscribing cross-sectional radius of a CTF column is denoted by r, the topographic features on the substrate of linear cross-sectional dimensions of the order of or larger than r are reproduced on the top surface of a CTF comprising nearly perpendicular columns. With r on the order of 30 to 300 nm, CTFs made from suitable inorganic materials can replicate topographic features on a submicron scale.

Thermal evaporation is the simplest of the PVD techniques used for growing CTFs. Other PVD techniques include electron-beam evaporation, sputtering, and laser ablation (7,8,25). However, thermal evaporation is the gentlest of the PVD techniques in that the substrate is not adversely impacted by the impinging atoms and molecules traveling with high momentums, a significant criterion for the high-fidelity replication of a fingerprint. Additionally, the high directionality of the evaporant flux facilitates columnar formation and growth (8). Furthermore, a significantly large and in-depth understanding of thermal evaporation exists in the scientific community, and so do several variations of this technique to achieve high-density CTFs (25).

Among the most recent variations is the CEFR technique, developed to fabricate high-fidelity replicas of biological templates such as the eyes of flies and the wings of butterflies (3,4). These templates have characteristic features on the micro- and nano-scales distributed over planar as well as curved surfaces. The CEFR technique is based on the combination of thermal evaporation with simultaneous substrate tilting (for obliquely directed vapor flux) and rapid rotation. The combination of substrate tilting and rapid rotation causes the columns of nanoscale diameters to grow upright (5,6), making the CEFR technique highly suitable for the solid-state acquisition of fingerprint topology, even for fingerprints exposed to environmental stress. The CEFR technique was used for all of the CTF fingerprint development in this research.

I.2.6. Pitfalls

Although the successful outcome of the research carried out can have distinct benefits for the latent fingerprint community, there are still obstacles to overcome. An obvious one is the size of the low-pressure chamber used for CTF deposition. This research project purposely targeted smaller items of evidence. Importantly, the research results suggest that a redesign of the low-pressure chamber is highly feasible. Additionally, the chamber(s) employed are currently laboratory-based systems, a limitation of current technology, and are not amenable to in-the-field work.

Also, the effects of ageing and environmental stresses on fingerprint residue texture are unknown. This is important because the CTF method requires a texture different from the substrate on which the fingerprint rests.

I.3. Statement of hypothesis or rationale for the research

The rationale for this research is that the topology of latent fingerprint residue is significantly different from that of the underlying nonporous substrates, that latent fingerprint development is amenable to CTF technology (2), and that it is superior to traditional methods used to develop fingerprints for specific substrates where current techniques are either inadequate or not ideal, provided that sufficient textural friction ridge detail is present.

Additionally, the development of friction ridge detail using CTFs is a single technique, which means it is applicable to different nonporous substrates and will obviate the need to perform complicated chemical or physical techniques – or combinations of techniques in a cascade – in order to obtain satisfactory development for specific substrates. Before comparison of developmental techniques could begin, we determined the underlying scientific basis of CTF development of latent fingerprints. This is in accordance with the 2009 report of the National Research Council (9), often referred to as the NAS report, which clearly stated that the scientific basis of forensic testing is critical.

Phase I of this research responded to the NAS report's suggestions by identifying the underlying scientific requirements for the CTF development of latent fingerprints on nonporous relevant forensic substrates identified in Table 1. Sections II.2.4 and III.1 of this report show successful optimization for the critical parameters of CTF fingerprint development.

Using the optimized CTF deposition parameters identified in Table 2, we investigated several evaporant materials for CTF development for each substrate tested in Phase II. The best evaporant material employed for the CTF development, the optimal CTF thickness, and the best-performing traditional technique used for all substrates investigated in our laboratory are summarized in Table 3. Traditional techniques were chosen based on results obtained by other investigators. The results presented in Table 4 showed that CTF development of latent fingerprints is superior to traditional development techniques for some forensically relevant substrates, is not superior for other substrates, and is equal to traditional techniques for other substrates.

II. Methods

II.1. General overview and research design

This was a two-year research program with the ultimate goal of ascertaining whether CTF acquisition of fingerprint topology is applicable to developing latent fingerprints in forensically relevant scenarios where current techniques are either inadequate or not ideal. The research was divided into overlapping phases that were actually a continuous, stepped process, where each sample (latent fingerprints on a specific substrate) progressed step-wise from Phase I, establishing optimum conditions for the deposition of CTFs on different types of substrates, to Phase II, a comparison of CTF-developed fingerprints with traditionally developed prints. As each substrate emerged from Phase I optimization, it was immediately taken into Phase II.

We first conducted a comprehensive study involving the optimization of the CTF development for a variety of nonporous forensically relevant substrates and using a variety of evaporant materials. Based on the understanding obtained, we went on to investigate the CTF development of (i) depleted fingerprints, (ii) partial bloody fingerprints, and (iii) fingerprints on discharged cartridge casings. Furthermore, we also compared the use of two different fluorescent materials for the deposition of CTFs on fingerprints. For all comparative studies, variability was limited by using the same finger of the same donor.

II.2. Initial comprehensive study

II.2.1. Forensically relevant substrates

The chosen substrates initially included: (i) brass (Alloy 260), (ii) stainless steel (Grade 420), (iii) the sticky and smooth sides of various adhesive tapes (Scotch® Duct, Gloss Finish Scotch® Multitask, Scotch® Masking, and Gorilla®), (iv) hard plastics (black and white acrylonitrile butadiene styrene (ABS), black and white nylon), (v) soft plastics (clear sandwich bags, white grocery bags, black garbage bags), (vi) woods (cherry and walnut, stained and sealed with polyurethane), (vii) partial bloody fingerprints on 420 grade stainless steel (whole human blood droplets from lanced fingertips), and (viii) discharged cartridge casings (9 mm Luger). All substrates—except discharged cartridge casings—were cut into 25 mm × 25 mm squares for deposition of a latent fingerprint per square.

II.2.2. Fingerprint collection procedure

All latent fingerprints were collected using a grooming procedure to ensure as much consistency as possible – first, throughout the optimization of the deposition parameters for CTF development, and then during comparative studies against traditional development techniques. The grooming procedure involved used the same finger at all times to limit variability. The finger was first cleansed with ethanol and allowed to dry. The fingertip was then swiped across the forehead, nose, and chin of the donor 20 times. Two fingerprints were laid down on a glass slide to remove excess sebaceous secretions, and then two fingerprints were laid down on the substrate of interest for processing. This procedure was then repeated until the desired number of samples was reached. The services of one fingerprint donor, unless otherwise noted, were utilized to minimize variability and maximize consistency between experiments. For each experiment, four duplicate fingerprints were collected. Fingerprints were allowed to age 24 h prior to development.

II.2.3. Evaporant materials

The evaporant materials utilized were selected because of their compatibility with PVD (8,25). Easily evaporated materials are desirable because they allow for high deposition rates to be achieved without producing unnecessary heat that could damage both the substrate under investigation and the latent fingerprint thereon. The evaporant materials chosen were: (i) chalcogenide glass of nominal composition $Ge_{28}Sb_{12}Se_{60}$, (ii) gold, (iii) nickel, (iv) magnesium fluoride, (v) germanium oxide, and (vi) a fluorescent evaporant Tris (8-hydroxyquinolinato) aluminum, more commonly known as Alq_3.

Alq_3 is an organometallic chelate that is typically used in organic light-emitting diodes, where variations of the quinoline structure can affect its luminescent properties [28]. Deposition of Alq_3 produces a developed fingerprint that is visible when exposed to short-wave ultraviolet radiation. Germanium oxide is a high-refractive-index material often used to make wide-angle lenses, magnesium fluoride is low-refractive-index material often used for anti-reflective coatings, gold and nickel are commonly used metals, and chalcogenide glass is an infrared transparent material often used for shortwave-infrared applications. This diversity of materials was chosen in order to best optimize deposition parameters on various substrates for the best contrast possible.

II.2.4. Optimization of CTF development

Prior to comparing the results of the CTF development technique with those of the traditional development techniques, a systematic series of experiments was carried out in order to determine the optimal CTF-deposition conditions necessary to achieve the highest quality of latent fingerprint development. The following parameters were varied within the limitations of a custom-made CEFR apparatus (2-6) in order to find their optimal values: (i) base pressure in the low-pressure chamber prior to deposition, (ii) average angle χ_v of the collimated vapor flux relative to the plane of the platform to which the substrate is affixed inside the low-pressure chamber, (iii) substrate rotation rate, (iv) deposition rate of the CTF, and (v) thickness (as measured by a quartz crystal monitor (QCM) within the low-pressure chamber) of the CTF. The base pressure was controlled using a turbo pump, the substrate rotation rate by the rotation motor, the deposition rate of the CTF through the electric current passed though a tungsten boat holding the evaporant material, and the CTF thickness by a QCM located close to the substrate inside the low-pressure chamber. The QCM also provides feedback for deposition control. The rocking motor was not used and the angle χ_v was held fixed during deposition. The evaporant material used for the optimization study was chalcogenide glass of nominal composition $Ge_{28}Sb_{12}Se_{60}$, and the underlying substrates were standard glass microscope slides.

II.2.5. Selected traditional development techniques

The CTF development technique was compared to traditional development techniques by following a split-fingerprint protocol. A fingerprint was deposited onto two 25mm$\times$ 12.5mm pieces of the selected substrate that were laid side by side, so that half of each fingerprint was placed on each piece. Each half was subsequently developed with either the CTF development technique or a traditional technique relevant to the specific substrate.

As indicated in Table 1, the traditional development techniques utilized included: (i) dusting with regular black powder, regular white powder, magnetic black powder, magnetic white powder, or a fluorescent powder (red, green, yellow, orange); and (ii) cyanoacrylate fuming (with cyanoblue dye when applicable) in a commercial chamber (Arrowhead Forensics, Lenexa, KS). The third traditional technique involved using either a pre-mixed liquid sold as Wetwop™, sticky-side powder (SSP), a small-particle reagent (SPR), leucocrystal violet (LCV), or protein dyes, amido black, and acid violet 17, as appropriate for the substrate of interest.

Following separate developments of both halves of each fingerprint, the two halves were reconnected and photographed for grading.

The performance of the CTF development technique was not comprehensively compared with that of VMD (15,16). Both techniques are similar in that they are based on evaporating a material in a low-pressure chamber, but they are also very different and are expected to produce very different outcomes.

II.2.6. Imaging of fingerprints

Both latent and developed fingerprints were photographed with a Nikon D3000 10.2 megapixel camera with a Nikon 60mm macro lens capable of 1:1 reproduction. The camera was attached to a custom stand that allowed photographs to be taken from the same viewing angle and under the same lighting conditions. Higher-magnification (10× to 40×) optical images of the fingerprints were acquired on a National stereo microscope partnered with a Moticam 1000 1.3 megapixel microscope camera.

A Hitachi S-3500N backscattered SEM, capable of resolving 4nm at 25kV and with magnification ranging from 15× to 100K×, was used to make images on which the columnar morphology of CTFs deposited on fingerprints could be resolved.

II.2.7. Subjective grading of fingerprints

All fingerprints were graded based on visual observation and comparison. Clarity, contrast, and visualization of observable detail of level one/two/three were all considered as developed fingerprints were compared side by side.

II.3. Depleted fingerprint series

Following the initial comprehensive study, the sensitivity of the CTF technique was studied by conducting depletion experiments. Interference from eccrine secretions forced us to redesign the fingerprint collection method for sensitivity studies. The depletion study was taken to the 300th fingerprint, but as the sebaceous secretions were depleting as each fingerprint was left, eccrine secretions were forming from the pores on the fingertips causing the fingerprints not to be depleted. Sebaceous secretions were collected as described in Section II.2.2, with the difference that a thin plastic wrap was wrapped around the finger to eliminate interference from eccrine secretions. This allowed us to collect every 2nd fingerprint until the 12th fingerprint.

The substrates used in the studies included: (i) stainless steel (Grade 420), (ii) brass (Alloy 260), (iii) anodized aluminum, and (iv) hard plastics (black and white ABS, black and white nylon). A split-print protocol was utilized for the substrates. The protocol required each 25mm x 25mm square of the substrate to be cut into two equal rectangles, which were then taped together to form the 25mm x 25mm square. A latent fingerprint was placed on the re-formed square, so that the fingerprint could be split into two halves, each to be developed by a different technique. This protocol allowed for the outcomes of two different techniques to be compared.

The two halves of a split print were labeled A and B. The half labeled A was developed with the CTF technique, and the half labeled B with a traditional technique. The depletion study was conducted twice for each substrate. The first time the split print labeled A was on the left with the split print labeled B on the right. The second time the split print labeled A was on the right and the split print labeled B on the left. This strategy compensated for any variability that could occur in how a fingerprint donor laid and put pressure on a substrate.

For the depletion series, the evaporant materials used included: (i) Alq_3, (ii) chalcogenide glass of nominal composition $Ge_{28}Sb_{12}Se_{60}$, (iii) gold, and (iv) nickel.

II.4. Partial bloody fingerprints

Inspired by the positive initial indication from the initial comprehensive study described in Section II.2, we went on to focus on partial bloody fingerprints on different types of nonporous forensically relevant substrates: (i) stainless steel (Grade 420), (ii) brass (Alloy 260), (iii) anodized aluminum, (iv) hard plastics (black and white ABS, black and white nylon) and (v) soft plastics (clear sandwich bag, white grocery bag, black garbage bag).

Sebaceous secretions were collected with the grooming procedure described in Section II.2.2. A split-print protocol described in Section II.3 was employed. Four fingerprint samples were collected for each substrate (split into two). Before each fingerprint was deposited, a drop of blood was added to the fingertip from a lanced fingertip. The lanced fingertip was not the same fingertip used to deposit the fingerprint.

For partial bloody fingerprints, the evaporant materials used included: (i) Alq_3, (ii) chalcogenide glass of nominal composition $Ge_{28}Sb_{12}Se_{60}$, (iii) gold, (iv) nickel and (v) (1,10-phenanthroline) tris[4,4,4-trifluoro-1-(2-thienyl)-1,3-butanedionato]europium(III) (more commonly known as $Eu(tta)_3phen$).

The traditional development techniques used are provided in Table 1. In addition, fluoroscein and hemascein were used.

II.5. Discharged cartridge casings

Fingerprints placed on 9 mm Luger cartridge casings prior to their subsequent discharge through a Ruger P95 pistol were developed by the hybrid cyanoacrylate-CTF technique used also for developing latent fingerprints on adhesive tapes. The fingerprint collection procedure is described in Section II.2.2.

A special fixture for mounting the discharged bullet casing to the platform in the low-pressure chamber had to be devised and fabricated. Furthermore, as the substrate (bullet casing) is not flat but possesses a convex cross section at the macroscopic length scale, the rocking motor was used to continually change the average vapor flux angle between 10° and 90° with a temporal period of ~ 9 s during deposition. Alq_3 was evaporated to deposit a 100-nm-thick CTF.

II.6. Fluorescent evaporant materials

In addition to Alq_3, we also studied the use of another fluorescent evaporant material: Eu(tta)3phen. Comparison was made with fingerprints developed with Alq_3 CTFs.

Sebaceous fingerprints were collected as described in Section II.2.2. Four fingerprints were collected on each substrate: (i) stainless steel (Grade 420), (ii) brass (Alloy 260), (iii) hard plastics (black and white ABS, black and white nylon) and (iv) glass. The split-print protocol explained in Section II.3 was adopted.

II.7. Preliminary comparison of CTF technique and VMD

Although a head-to-head comparison between CTF development and VMD development was not envisaged for this research project, a preliminary comparative study was undertaken towards the end of the project period. The morphologies of the thin films deposited on fingermarks on glass were examined using a scanning electron microscope. Comparison was also made for the development of fingerprints on four types of plastics (clear sandwich bags, white grocery bags, smooth side of Gloss Finish Scotch® Multitask tape, and black garbage bags) and partial bloody fingerprints on stainless steel, using the split-print methodology described in Sec. II.3.

II.8. Objective fingerprint grading system

Fingerprints were initially graded based on visual observation and comparison, where clarity, contrast, and visualization of observable detail of levels one/two/three were all considered. All developed fingerprints were compared side by side, as discussed in Section II.2.7. Soon, we recognized the need to have a completely objective system for grading quality.

Thus, an objective quantitative grading system was devised that requires the successive use of three separate programs that collectively transform a photograph of a fingerprint into a multicolor-coded quality map, change the colors into a red-green-blue (RGB) spectrum, count the number of those pixels whose color corresponds to regions of definitive identifiable minutiae, and calculate the percentage of the fingerprint area that has definitive identifiable minutiae. We found this quality grading system useful for evaluating the efficacy the CTF development method and for comparing two development methods using the split-fingerprint approach.

Using the quantitative quality grading system requires the following: (1) photographing a fingerprint before and after development; (2) placing a scale in the photographic plane parallel to the plane of the fingerprint, and (3) a viewable scale in the resulting photograph in order to reduce as much as possible errors in subsequent processing with the three computer programs.

The first program employed is the Universal Latent Workstation (ULW) developed by the Federal Bureau of Investigation (FBI) to help fingerprint examiners to characterize fingerprints and then upload them to the Automated Fingerprint Identification System (AFIS). Once a photograph has been imported into the program as an image, the user is prompted to provide information about pixels per inch (ppi) of the image. The program supports only images having a resolution of 1000 ppi. The scale visible within the photograph's frame helps the program identify the number of pixels that fit within a distance of 1 inch. The program then converts the image to the proper resolution and into grayscale.

Within this program, there is a subset of features called the *Extended Feature Set* wherein an *Image Quality* map is applied to the image of the latent fingerprint. The Image Quality map contains the colors black, red, yellow, and green – corresponding to the background, debatable ridge flow, debatable minutiae, and definitive minutiae, respectively. In this raw quality map, the grayscale photograph of the fingerprint is still visible in the background. Next, the grayscale levels, brightness, and contrast are adjusted to leave only the four quality map colors visible. This is done by dragging the color adjustment bar at the top of the ULW program fully to the right. We refer to the quality map altered in this way as *darkened*.

The resulting *darkened* quality map is exported as a .bmp file and uploaded into the second program, which is an image editing program called GIMP (28). In this program, the quality map colors assigned by the ULW are transformed into RGB color values represented in digital 8-bit notation: black is (0, 0, 0), blue (0, 0, 255), yellow (255, 255, 0), and white (255, 255, 255). These values correspond to (0, 0, 0), (0, 0, 1), (1, 1, 0), and (1, 1, 1) when using arithmetic notation. The resulting image is saved for a pixel-counting algorithm to be used on it. In the GIMP color scheme, black corresponds to background, blue to debatable ridge flow, yellow to debatable minutiae, and white to definitive minutiae. We decided to rate the image quality based on the percentage of the image area that is white, i.e., identified as having definitive minutiae.

This is done using a Mathematica® (29) program devised specially for this purpose. In this program, the image is represented as an N x M matrix where N is the width of the image in pixels and M is the height of the image in pixels. Each element of this matrix contains the RGB value of the pixel in the image with the same coordinates. This representation is analogous to a vector field in which each coordinate in a 2-Dimensional plane has a 3-Dimensional vector associated with it. By our selection of the RGB values we simplify this vector field to a scalar field by averaging each of the RGB values. Thus, black (0, 0, 0) becomes 0, blue (0, 0, 1) becomes 1/3, yellow (1, 1, 0) becomes 2/3, and white (1, 1, 1) becomes 1, giving us an N x M matrix where each element is 1 of 4 possible numbers. Since we are only concerned with the occurrence of each value, we simplify the matrix into a list of its elements, reducing our task to tallying the number of times that each value appears in the list and the calculating the percentage of the image each color represents after subtracting the black background pixels. We utilized the percentage of the image identified as containing definitive minutiae before and after development as a measure of the performance of the development technique as well as for comparing different fingerprint development techniques when using the split fingerprint method.

The program commands in Mathematica® (either version 7 or 8) are outlined as follows:

(M1) a = Import["C:\\Insert Image from GIMP Pathname Here"];
(M2) b = ColorQuantize[a,5];
(M3) n = ImageDimensions[b];
(M4) c = ImageData[b];

```
(M5)  e = Table[Mean [c[[A]][[B]]], {A, 1, n[[2]]}, {B, 1, n[[1]]}];
(M6)  f = Flatten[e];
(M7)  g = MatrixForm[Sort[Tally[f], #1[[1]] < #2[[1]]&]];
(M8)  p = Tally[f];
(M9)  ell = Dimensions[p];
(M10) m = ell[[1]];
(M11) sum = Total[Table[g[[1]][[k]][[2]],{k,1,m}]];
(M12) Fraction[MatrixForm[Table[{3*g[[1]][[k]][[1]], N[100*g[[1]][[k]][[2]] /
      ((sum - g[[1]][[1]][[2]])) "%", 2]}, {k,2,m}]]
```

The command M1 imports the desired image into Mathematica® subsequent to its processing with GIMP. Once the image has been imported, use of command M2 downgrades the photograph to a given number of colors. This number should be selected to be as low as possible without eliminating one of the colors assigned in GIMP. This must be done as when the image is exported from the ULW it may contain stray pixels that are not one of the four assigned colors. Ideally this value would be 4 but in practice it is selected between 5 and 7. The stray pixels account for a fraction of a percentage of the total image.

Next, command M3 is used in order to call up the dimensions of the image modified with command M2 so that pixel counters can be iterated in future commands. Command M4 generates a matrix with the same dimensions as the photograph modified by command M2 in which each matrix component is the RGB value of a pixel corresponding to that matrix element. Next, command M5 takes the average of the RGB values generated by command M4 compressing the RGB value into a single number. The colors assigned in GIMP were selected so that this average value would come to 0 for black, 1/3 for blue, 2/3 for yellow and 1 for white. The simplified matrix from command M5 is then further reduced to a list by command M6. Command M7 then tallies the number of times that each value appears in this list, sorts the tally results in ascending order according to the value of the average RGB value from command M5 and reports the results in the form of a matrix with the average RGB value in the left column and the number of times of its occurrence in the right column. Command M8 utilizes the tally command again to give the total number of elements in the list generated by command M6. This is done again in order to use this information in future iterations. Command M9 gives the dimension of the matrix that has the color and its number count, for use in future iterations. Command M10 is then used to give the number of columns that appear after the execution of command M8 so that its result can be used by commands M11 and M12 as the upper limit of an iterator. Command M11 then gives the total number of all of the pixels counted by summing the results of command M7. Finally, command M12 reports the percentage of the image that is composed of each color of interest. Colors are identified by their average RGB values multiplied by 3 to give each one as a whole number: 1 for blue, 2 for yellow, and 3 for white. The percentage reported is calculated from the blue, yellow and white areas of the image; black pixels are excluded. This allows us to consider only the print portion of the photograph when comparing the photographs of a fingerprint before and after development.

III. Results

III.1. Statement of results

III.1.1. Initial comprehensive study

III.1.1.1. *Phase I: Optimization of CTF development*

Five parameters were varied for CTF optimization in Phase I research (as discussed in Section II.2.4): base pressure, average vapor flux angle χ_v, CTF deposition rate, substrate rotation rate, and CTF thickness. The values of these parameters specifically used for optimization are presented in Table 2, along with the optimal value of each parameter determined by visual observation of clarity, contrast, and level one/two/three detail of the developed fingerprints. The optimal values of four of the five parameters turned out to be quite similar to those used in the proof-of-principle experiments (2), the sole exception being the base pressure prior to the beginning of the CTF deposition.

Whereas the base pressure was 4.0×10^{-6} Torr or lower in the predecessor studies (2), it was determined that just 1.0×10^{-4} Torr would suffice for fingerprint development. The adequate base pressure thus determined is moderately low, which greatly reduces the requirements on CEFR apparatus for fingerprint development. This finding means that an on-scene field-forward technique could be designed, and the subsequent expense for CTF fingerprint development equipment will be less than originally thought, and the time required to pump down to the base pressure significantly reduced.

The efficacy of the CTF development technique is brought out by the five images presented in Fig. 3. Photographs of a fingerprint on a glass slide are shown in Figs. 3A and 3B, respectively, before and after development using the optimal conditions identified in Table 2. The latent fingerprint is invisible (Fig. 3A), but the optimal deposition of a chalcogenide-glass CTF on it makes it clearly visible (Fig. 3B). The 30× magnified image in Fig. 3C, obtained on an optical microscope, shows level-three pore detail. The top-view SEM image at 5000× magnification in Fig. 3D is in agreement with the columnar morphology of the CTF deposited atop the latent fingerprint (2). Far more convincingly, however, the cross-sectional SEM image at 6000× magnification in Fig. 3E shows not only a generally upward columnar morphology but also the conformal shape of the deposited CTF.

The optimal deposition parameters presented in Table 2 were obtained for just one combination of the evaporant material (chalcogenide glass) and the substrate (glass slide). Except for the CTF thickness, all other optimal parameters in Table 2 were found to also deliver the best fingerprint development for all other combinations of the evaporant material and substrate. However, the optimal CTF thickness did depend on the evaporant material. For instance, 50-nm-thick CTFs of gold provided optimal contrast, whereas the optimal thickness of a CTF of chalcogenide glass turned out to be 20 times higher. For all other combinations of the evaporant material and substrate tested, the optimal CTF thickness was found to lie between 50 and 1000 nm, both inclusive.

Meta-analysis of the data collected resulted in the identification of the best evaporant material for the CTF development technique as well as the traditional development technique that gave the best results for a wide range of non-porous substrates upon which fingerprints are commonly found at crime scenes (11,12). The best evaporant material and the optimal CTF thickness—along with the best traditional technique—for all substrates investigated are provided in Table 3.

III.1.1.2. *Phase II: Comparison with selected traditional development techniques*

For several of the substrates investigated, the CTF development technique provided results superior to those of all traditional development techniques investigated. For some others, the CTF-developed fingerprint and the best traditionally developed fingerprint were of the same quality. Both groups of substrates are listed in Table 4, as are the substrates for which the best traditional development technique outperformed the CTF development technique.

Thus, the CTF development technique is not universally applicable, as can be expected from any technique to develop latent fingerprints. Development by the deposition of a CTF is suitable typically only for non-porous substrates, and the fragility of some substrates poses development difficulties. Latent fingerprints on some of the substrates investigated were difficult to develop as the temperature within the low-pressure chamber can sometimes reach 40 ºC. Some substrates—such as soft black plastic sheets (black garbage bags)—curled up upon development. In the case of Scotch® Duct tape, the cords within the adhesive started pulling out of the substrate of the tape. The deformation of some substrates (such as soft plastics and adhesive tapes) inside the low-pressure chamber limited the types of evaporant materials that could be used for the CTF development of latent fingerprints. In many cases, however, this deformation could be minimized by carefully shuttering the source of the thermal energy and minimizing the time that the substrate was unnecessarily exposed.

Some substrates in Table 3 are marked with an asterisk. Whereas the CTF development technique did not produce satisfactory results with these substrates, pre-fuming the latent fingerprint on these substrates with cyanoacrylate followed by the CTF development technique produced the best outcomes. Thus, latent fingerprints on the smooth sides of Scotch® Duct tape (Fig. 4) and Gorilla® tape (Fig. 5) developed very well using cyanoacrylate fuming first, followed by the deposition of a 50-nm-thick CTF of gold. Quite likely, the successful development was facilitated by the layer of cyanoacrylate polymer on the ridge detail, which provided better definition of the fingerprint topology, revealed by the CTF deposited on top of the enhanced topology. The hybrid cyanoacrylate-CTF technique appears promising and requires further research.

All adhesive tapes were able to withstand the higher than room temperature in the low-pressure chamber very well. CTF development with gold as the evaporant material worked very well – and better than all traditional development techniques employed – with fingerprints laid on the smooth sides of three of the four adhesive tapes investigated. As an example, level-three detail is clearly observable in Fig. 6, showing a fingerprint on the smooth side of Gloss Finish Scotch® Multitask tape which was developed with a 50-nm-thick CTF of gold. Other substrates, such as the smooth sides of Scotch® Duct tape (Fig. 4) and Gorilla® tape (Fig. 5), did require application of the hybrid cyanoacrylate-CTF development technique. The sole exception was the smooth side of Scotch® Masking tape, for which no development technique delivered a satisfactory outcome.

The CTF development technique also performed well on latent fingerprints on the sticky sides of

Scotch® Duct tape, Gorilla® tape, and Gloss Finish Scotch® Multitask tape. However, equally satisfactory performance was delivered by the traditional development technique of the application of Wetwop™, as exemplified in Figs. 7–9. Figure 10 shows that the cyanoacrylate fuming (with cyanoblue dye) yielded a superior result on the sticky side of Scotch® Masking tape than the CTF development technique.

The CTF development technique worked very well with latent fingerprints deposited on all three types of soft plastics: black garbage bags, white grocery bags, and clear sandwich bags. For black garbage bags (Fig. 11) and clear sandwich bags (Fig. 12), the CTF development technique provided much better contrast for visualization than any traditional development techniques. Even on white grocery bags (Fig. 13), the CTF development technique performed as well as dusting with black magnetic powder, the best traditional development technique for the specific substrate.

The CTF development technique did not show superior performance for latent fingerprints on hard plastics, the best results obtained with 100-nm-thick CTFs of Alq_3. As seen in Figs. 14–17, the CTF development technique performed as well as dusting with red fluorescent powder for latent fingerprints on black ABS (Fig. 14) and white nylon (Fig. 17). On white ABS (Fig. 15) and black nylon (Fig. 16), respectively, dusting with black magnetic powder and red fluorescent powder outperformed the CTF development technique.

Wood substrates are typically porous, except when sealed with a polyurethane or equivalent coating. Fingerprints were deposited on smooth substrates of commercial samples of cherry and walnut woods that had been stained and sealed. None of the selected evaporant materials worked well, with the exception of Alq_3. When exposed to short-wave ultraviolet radiation, the Alq_3-developed fingerprints possessed suitable contrast for identification of fingerprint ridge detail. None of the chosen traditional methods performed satisfactorily.

III.1.2. Depleted fingerprint series

For the depleted fingerprint series, the evaporant materials used included: (i) Alq_3, (ii) chalcogenide glass of nominal composition $Ge_{28}Sb_{12}Se_{60}$, (iii) gold, and (iv) nickel. The traditional techniques used included: (i) dusting with red fluorescent powder, black powder, and white powder; (ii) cyanoblue; and (iii) cyanoacrylate fuming. A hybrid method was also used on brass where cyanoacrylate fuming was done before the fingerprint was dusted with black powder. The fingerprints subjected to comparative study were the 2nd and the 12th in the depletion series.

Table 5 is a summary of the results. Figure 18 shows the before and after development of fingerprints of the depletion series on black ABS. Figure 19 presents a similar example on brass.

The CTF technique worked well on brass, stainless steel, anodized aluminum, black ABS, and white nylon. The CTF technique worked poorly on white ABS and black nylon, but the traditional development techniques yielded poor results as well. The sensitivity of the CTF technique was greater than of the traditional development techniques on brass and anodized aluminum, but similar on stainless steel and all the hard plastics.

III.1.3. Partial bloody fingerprints

All evaporant materials tested provided satisfactory development of partial bloody fingerprints on different substrates, as noted in Table 6.

An example of CTF development on both the bloody and latent portions of the fingerprint is shown in Fig. 20, where the deposition of a 100-nm-thick CTF of nickel developed both the patent and the latent portions of a partial bloody fingerprint on stainless steel in a single step. The left panel of the figure shows the development resulting from cyanoacrylate fuming followed by dusting with regular black powder, which is the traditional technique that gave the best results in our laboratory. The CTF development technique clearly performed better. Another example of the superior development with the CTF technique over the traditional development techniques is shown on brass in Fig. 21.

Tables 7 and 8 clearly show that the CTF development technique was either superior to or as good as traditional attempts to develop partial bloody fingerprints using chemical techniques on all substrates tested. Deposition of either a gold CTF or a chalcogenide-glass CTF yielded superior results in comparison to those of traditional development techniques, on both hard and soft plastics. However, the deposition of gold CTFs performed similarly to traditional development techniques on anodized aluminum, and the deposition of nickel CTFs performed similarly to traditional development techniques on brass. Deposition of Alq_3 CTFs was definitely superior to traditional development techniques. Most significantly, the CTF technique was able to develop both latent and bloody parts of the fingerprints in one step with good results.

III.1.4. Discharged cartridge casings

Discharged cartridge casings have no traditionally accepted method for development of latent fingerprints on them, and many of the previously discussed methods have been applied in order to find a method with acceptable performance (30). In this study, fingerprints placed on cartridge casings before the discharge of a 9 mm Luger from a Ruger P95 pistol were developed by the hybrid cyanoacrylate-CTF technique used also for developing latent fingerprints on adhesive tapes.

The fingerprints of two donors were tested. The fingerprints of one donor – whose fingerprints were used for most of the work reported here – did not develop at all, whether the CTF technique was used or any of the selected traditional techniques was used. However, as can be observed in Fig. 22, under short-wave ultraviolet illumination, the developed fingerprint of the second donor has sufficient detail for identification. Clearly, the CTF development of fingerprints on discharged cartridge casings requires intensive study in the future.

III.1.5. Fluorescent evaporant materials

CTFs of both fluorescent evaporant materials tested – Alq_3 and $Eu(tta)_3phen$ – were able to develop fingerprints, depending on the substrate. Development with a $Eu(tta)_3phen$ CTF was superior to development with an Alq_3 CTF on white ABS and black nylon, but the reverse was true on glass and stainless steel. Figure 23 shows the comparison of the two evaporant materials on glass. The left panel shows that development with the Alq_3 CTF provides clear details, but the right panel shows overdevelopment with the $Eu(tta)_3phen$ CTF.

The development was similar with both evaporant materials on white nylon, black ABS, and brass. Both evaporant materials produced clear details, as is clear from Fig. 24 for development on white nylon. A summary of all results is provided in Table 9.

III.1.6. Objective fingerprint grading system

Although subjective grading, as described in Section II.2.7, was used in the initial comprehensive study of Section II.2, the objective grading system, devised by us and described in Section II.6, was also used in all subsequent work. The subjective grading system is much too coarse in comparison to the devised objective grading system that rated the latent fingerprint in Fig. 25 at 2.3% and the cyanoacrylate-fumed fingerprint at 58%. The higher that the objective grading, the more is the ridge detail evident in it. The efficacy of the objective grading system in relation to actual identification is a topic for further research.

III.1.7. Preliminary comparison of CTF technique with VMD

Although both techniques involve the deposition of a material onto latent sebaceous fingerprints on a substrate in a vacuum chamber, there are many differences between the two techniques. Whereas the film deposited with the CTF technique has a columnar morphology, we found in a preliminary comparative study that that the film deposited with VMD comprises islands rather than columns, as may be gathered from the cross-sectional SEM images in Fig. 26.

Using the split-print methodology, we determined that the CTF technique was superior to VMD for developing latent fingerprints on clear sandwich bags and partial bloody fingerprints on stainless steel. The CTF technique and VMD were similar in their ability to develop latent fingerprints on glass but there was more contrast when the CTF technique was used. VMD was superior to the CTF technique for developing latent fingerprints on white grocery bags and the smooth side of Scotch® Multitask tape. Neither technique worked well for latent fingerprints on black garbage bags. A comprehensive comparative study is needed.

III.2. Tables

TABLE 1—Combinations of forensically relevant substrates and traditional development techniques investigated during the initial comprehensive study of Section II.2.

Forensically Relevant Substrate	Specifically	Traditional Development Techniques Studied
Brass	Alloy 260	Regular powder, magnetic powder, fluorescent powders, cyanoacrylate fuming
Stainless Steel	420 Grade	Regular powder, magnetic powder, fluorescent powders, cyanoacrylate fuming
Adhesive Tapes (sticky and smooth sides)	Scotch® Duct, Gloss Finish Scotch® Multitask, Scotch® Masking, Gorilla®	Wetwop™, SSP, SPR, cyanoacrylate fuming, cyanoblue, powders
Hard Plastics	Nylon, ABS	Regular powder, magnetic powder, fluorescent powders, cyanoacrylate fuming
Soft Plastics	Black garbage bag, White grocery bag, Clear sandwich bag	Regular powder, magnetic powder, fluorescent powders, cyanoacrylate fuming
Stained and Sealed Woods	Cherry, Walnut	Regular powder, magnetic powder, fluorescent powders, cyanoacrylate fuming
Partial Bloody Fingerprints on Stainless Steel	420 Grade	Regular black powder, LCV, amido black, cyanoacrylate fuming, cyanoblue
Discharged Cartridge Casing	9 mm Luger	NA

TABLE 2—Optimized parameters for the deposition of a CTF of chalcogenide glass on a latent fingerprint on a glass slide.

Parameter	**Values Investigated for Optimization**	**Optimal Value**
Base Pressure (10^{-4} Torr)	0.028, 0.13, 1.0, 400	1.0
Average Vapor Flux Angle χ_v	5º, 10º, 15º, 20º, 30º, 60º, 90º	20º
CTF Deposition Rate (nm s^{-1})	0.5, 1.0, 2.0, 5.0	1.0
Substrate Rotation Rate (rpm)	4.5, 15, 60, 180	180
CTF Thickness (nm)	200, 500, 800, 1000, 1500, 2000	1000

TABLE 3—The evaporant material employed for the CTF development, the optimal CTF thickness, and the traditional technique used for every substrate investigated in the initial comprehensive study of Section II.2. The asterisk indicates that the substrate was subjected to cyanoacrylate fuming before being subjected to the CEFR method, in order to obtain the best CTF development.

Substrate	**Evaporant Material**	**CTF Thickness (nm)**	**Traditional Development Technique**
Brass	Chalcogenide Glass	1000	Black powder/ Cyanoacrylate
Stainless Steel	Chalcogenide Glass	1000	Cyanoacrylate + cyanoblue
Stainless Steel	Nickel	100	Cyanoacrylate + cyanoblue
Stained & Sealed Walnut	Alq_3	100	White magnetic powder
Stained & Sealed Cherry	Alq_3	100	Black magnetic powder
Black ABS	Alq_3	100	Red fluorescent powder
White ABS	Alq_3	100	Black magnetic powder
Black Nylon	Alq_3	100	Red fluorescent powder
White Nylon	Alq_3	100	Red fluorescent powder
Black Soft Plastic (Garbage bag)	Nickel	100	White magnetic powder
White Soft Plastic (Grocery bag)	Nickel	100	Black magnetic powder
Clear Soft Plastic (Sandwich bag)	Gold	50	Cyanoacrylate

Scotch® Duct Tape – sticky side	Nickel	100	Wetwop™
Scotch® Duct Tape – sticky side	Gold	50	Wetwop™
Scotch® Duct tape – smooth side*	Gold	50	Cyanoacrylate + cyanoblue
Scotch® Masking tape – sticky side	Nickel	100	Cyanoacrylate + cyanoblue
Scotch® Masking tape – sticky side	Gold	50	Cyanoacrylate + cyanoblue
Scotch® Masking tape – smooth side	N/A	N/A	N/A
Gorilla® tape – sticky side	Gold	50	Wetwop™
Gorilla® tape – smooth side*	Gold	50	Cyanoacrylate
Gloss Finish Scotch® Multitask tape – sticky side	Gold	50	Wetwop™
Gloss Finish Scotch® Multitask tape – smooth side	Gold	50	Cyanoacrylate
Partial Bloody Fingerrprint on Stainless Steel	Nickel	100	Cyanoacrylate + cyanoblue
Discharged Cartridge Casing*	Alq_3	100	N/A

TABLE 4—Comparison of the performances of the CTF development technique and the traditional development technique in the initial comprehensive study of Section II.2. The asterisk indicates that the substrate was subjected to cyanoacrylate fuming before being subjected to the CEFR method, in order to obtain the best CTF development.

Substrate	**CTF Development is Superior**	**Traditional Development is Superior**	**Equal Quality**
Brass	-	-	Yes
Stainless Steel	-	Yes	-
Stained & Sealed Walnut	Yes	-	-
Stained & Sealed Cherry	Yes	-	-
Black ABS	-	-	Yes
White ABS	-	Yes	-
Black Nylon	-	Yes	-
White Nylon	-	-	Yes
Black Soft Plastic (Garbage bag)	Yes	-	-
White Soft Plastic (Grocery bag)	-	-	Yes
Clear Soft Plastic (Sandwich bag)	Yes	-	-
Scotch® Duct Tape – sticky side	-	-	Yes
Scotch® Duct Tape – smooth side*	Yes*	-	-
Scotch® Masking Tape – sticky side	-	Yes	-

Scotch® Masking Tape – smooth side	-	Yes	-
Gorilla® Tape – sticky side	-	-	Yes
Gorilla® Tape – smooth side*	Yes*	-	-
Gloss Finish Scotch® Multitask Tape – sticky side	-	-	Yes
Gloss Finish Scotch® Multitask Tape – smooth side	Yes	-	-
Partial Bloody Fingerprint on Stainless Steel	Yes	-	-
Discharged Cartridge Casing	Yes*	N/A	-

TABLE 5—Comparison of the performances of the CTF development technique and traditional development techniques for depleted fingerprints on forensically relevant substrates.

Substrate	**Development with CTF Evaporant Material**			**Traditional Development Technique**		
	Alq_3	**Chalcogenide glass**	**Gold**	**Red fluorescent powder**	**Regular Powder**	**Cyanoacrylate fuming with cyanoblue**
Black ABS	Poor or none	Small amount	Small amount	None	Very small or none	n/a
White ABS	Poor or none	No	None	None	None	None*
Black Nylon	Poor or none	Barely any	None	None	Very small amount	n/a
White Nylon	Poor or none	None	Small amount	None	None	n/a
Stainless Steel	n/a	Majority	n/a	n/a	n/a	Majority
Anodized Aluminum	Full	n/a	Barely any	n/a	Partial faint	None
Brass	n/a	Majority	n/a	n/a	n/a	Partial faint *

*Developed with cyanoacrylate fuming and dusting by black powder

TABLE 6—Evaporant materials for successful CTF development of partial bloody fingerprints on various substrates.

Substrate	**CTF Evaporant Material**
Black ABS, White ABS, Black Nylon, White Nylon, Clear Soft Plastic, Anodized Aluminum	Gold
Black ABS, White ABS, White Nylon, Clear Soft Plastic	Chalcogenide Glass
Black ABS, Black Soft Plastic, White Soft Plastic	$Eu(TTA)_3phen$
White Nylon, Clear Soft Plastic, Brass	Nickel
Brass, Anodized Aluminum	Alq_3

Table 7—Comparison of the performances of the CTF development technique and traditional development techniques for partial bloody fingerprints on hard and soft plastic substrates.

Substrate	**Development with CTF Evaporant Material**		**Traditional Development Technique**		
	Chalcogenide glass	**Gold**	**Acid Violet 17**	**Amido Black**	**Powder**
Black ABS	Some and faint	Some or all	None	Some	None
White ABS	Some and faint	Some or all	None	Some	None
Black Nylon	n/a	Some or all	None	Some	None
White Nylon	Some and faint	Some or all	None	Some	None
Clear Soft Plastic	Small	Some	None	Some	None

Table 8—Comparison of the performances of the CTF development technique and traditional development techniques for partial bloody fingerprints on anodized aluminum and brass.

Substrate	**Development with CTF Evaporant Material**			**Traditional Development Technique**		
	Alq_3	**Nickel**	**Gold**	**Fluoroscein**	**Hemascein**	**Powder**
Anodized Aluminum	Full	n/a	Some but faint	n/a	None	Some
Brass	Full	Some but faint	n/a	n/a	None	Some

Table 9—Comparison of two fluorescent evaporant materials for CTF development of fingerprints on forensically relevant substrates.

Substrate	**Alq_3**	**$Eu(tta)_3phen$**	**Superior Development**
White ABS	Poor development	Poor development	$Eu(tta)_3phen$
Black Nylon	No development	Some development	$Eu(tta)_3phen$
White Nylon	Development but faint	Development but faint	Equal
Black ABS	Development but faint	Development but faint	Equal
Brass	Clear development	Clear development	Equal
Stainless Steel	Clear development	No development	Alq_3
Glass	Clear development	No development	Alq_3

III.3. Figures

FIG. 1—Illustration of the CTF concept using a toy called Pin Point Impression comprising parallel, identical, thin cylindrical pins. Left panel: Pins over a flat surface. Right panel: Pins over an undulating surface.

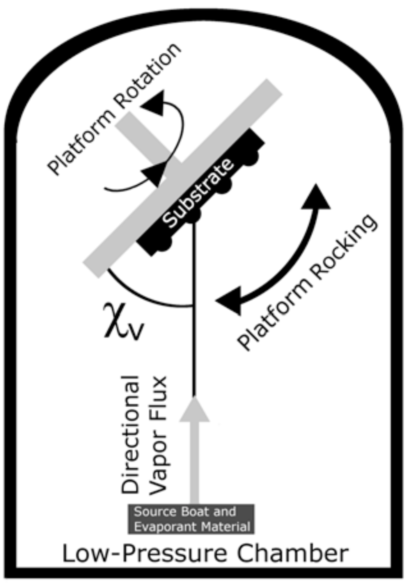


FIG. 2—Schematic of the CEFR method. In a low-pressure chamber, a collimated vapor flux is directed towards a substrate mounted on a platform that rotates rapidly about a central normal axis. The platform may also be made to rock slowly about an axis lying wholly in the platform plane so that the angle χ_v between the average direction of the vapor flux and the platform plane varies periodically, provided the exposed surface of the substrate is significantly lenticular.

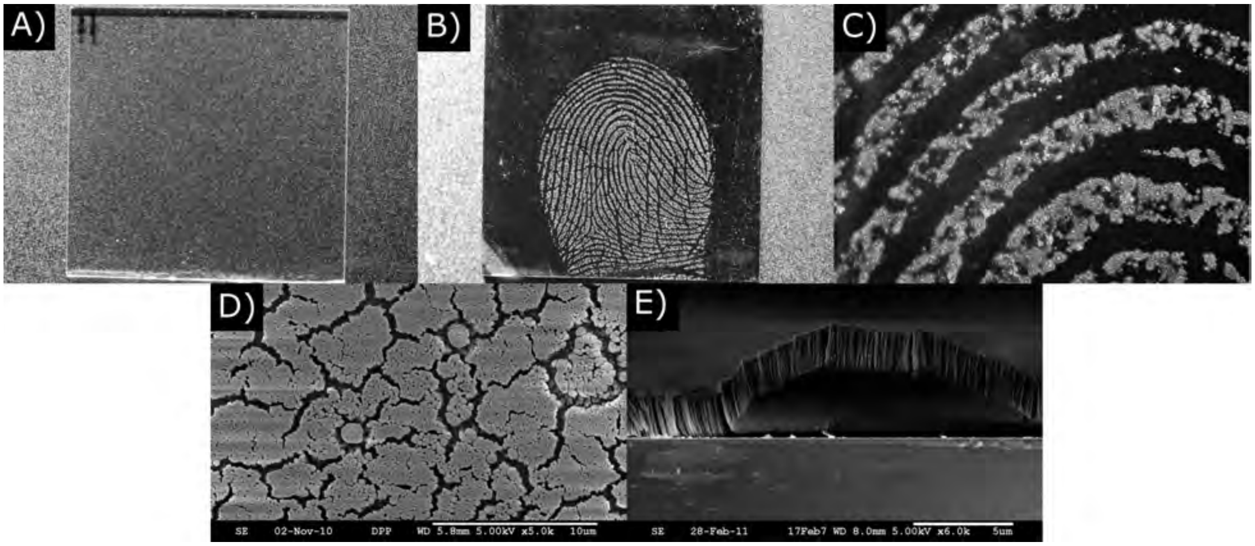


FIG. 3—(A) Photograph of a latent fingerprint on a glass slide before CTF development; (B) photograph of the developed fingerprint after a 1000-nm-thick CTF of chalcogenide glass had been deposited thereon under the optimal conditions identified in Table 2; (C) a 30× magnified image on an optical microscope of the developed fingerprint, showing level-three pore detail very clearly; (D) top-view SEM image of the developed fingerprint at 5000× magnification; and (E) cross-sectional SEM image of a ridge in the developed fingerprint at 6000× magnification.

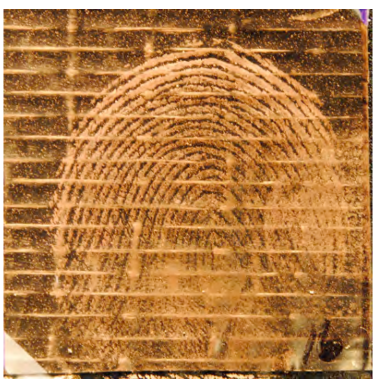


FIG. 4—Fingerprint on the smooth side of Scotch® Duct tape developed by a hybrid technique involving pretreatment of the latent fingerprint by cyanoacrylate fuming followed by the deposition of a 50-nm-thick CTF of gold.

FIG. 5—Same as Fig. 4, but for the smooth side of Gorilla® tape.

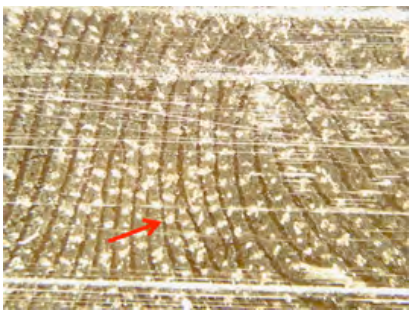


FIG. 6—Magnified optical image of a fingerprint on the smooth side of Gloss Finish Scotch® Multitask tape developed by the deposition of a 50-nm-thick CTF of gold. Pore detail is present in the developed fingerprint (arrow).

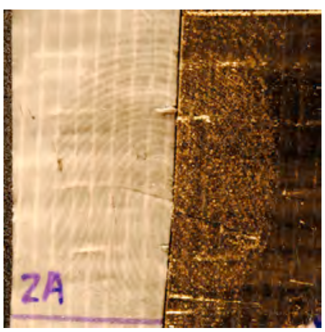


FIG. 7—Fingerprint on the sticky side of Scotch® Duct tape developed either (left) by the use of Wetwop™ or (right) by the deposition of a 100-nm-thick CTF of nickel.

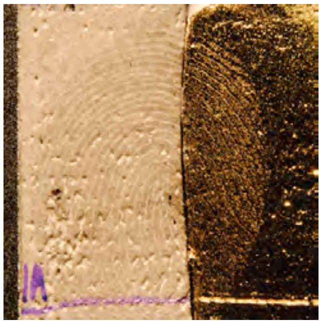


FIG. 8—Fingerprint on the sticky side of Gorilla® tape developed either (left) by the use of Wetwop™ or (right) by the deposition of a 50-nm-thick CTF of gold.

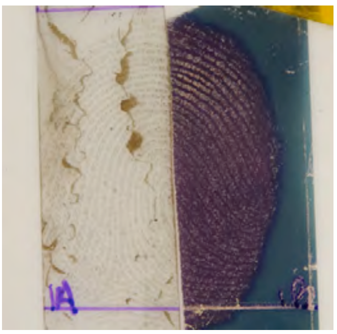


FIG. 9—Same as Fig. 8, except for the sticky side of gloss finish Scotch® multitask tape.

FIG. 10—Fingerprint on the sticky side of Scotch® Masking tape developed either (left) by the use of Wetwop™ or (right) by the deposition of a 100-nm-thick CTF of nickel.

FIG. 11—Fingerprint on a black garbage bag (soft plastic) developed either (left) by the use of white magnetic power or (right) by the deposition of a 100-nm-thick CTF of nickel. Level-three detail is clearly seen in the CTF-developed fingerprint.

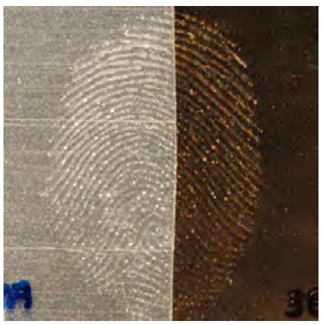


FIG. 12—Fingerprint on a clear sandwich bag (soft plastic) developed either (left) by the use of cyanoacrylate fuming or (right) by the deposition of a 50-nm-thick CTF of gold. Level-three detail is clearly seen in the CTF-developed fingerprint.

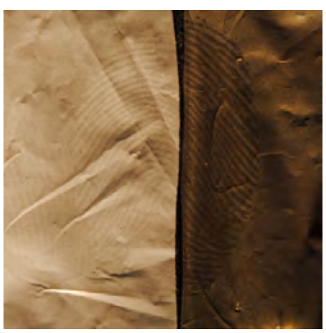


FIG. 13—Fingerprint on a white grocery bag (soft plastic) developed either (left) by the use of black magnetic power or (right) by the deposition of a 100-nm-thick CTF of nickel.

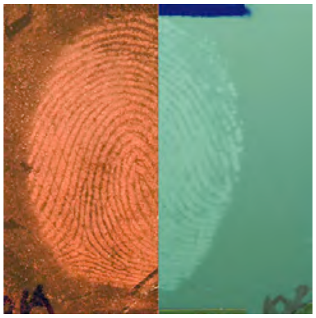


FIG. 14—Fingerprint on black ABS developed either (left) by the use of red fluorescent powder or (right) by the deposition of a 100-nm-thick CTF of Alq_3. Short-wave ultraviolet illumination is needed to see the detail in the CTF-developed part of the fingerprint.

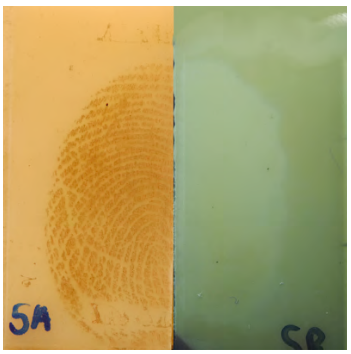


FIG. 15—Fingerprint on white ABS developed either (left) by the use of black magnetic powder or (right) by the deposition of a 100-nm-thick CTF of Alq_3. Short-wave ultraviolet illumination is needed to see the detail in the CTF-developed part of the fingerprint.

FIG. 16—Fingerprint on black nylon developed either (left) by the use of red fluorescent powder or (right) by the deposition of a 100-nm-thick CTF of Alq_3. Short-wave ultraviolet illumination is needed to see the detail in the CTF-developed part of the fingerprint.

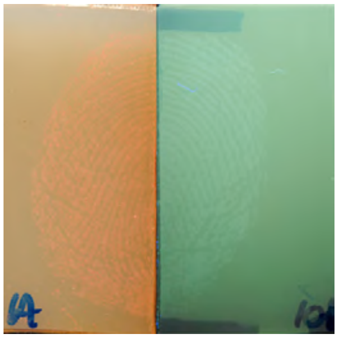
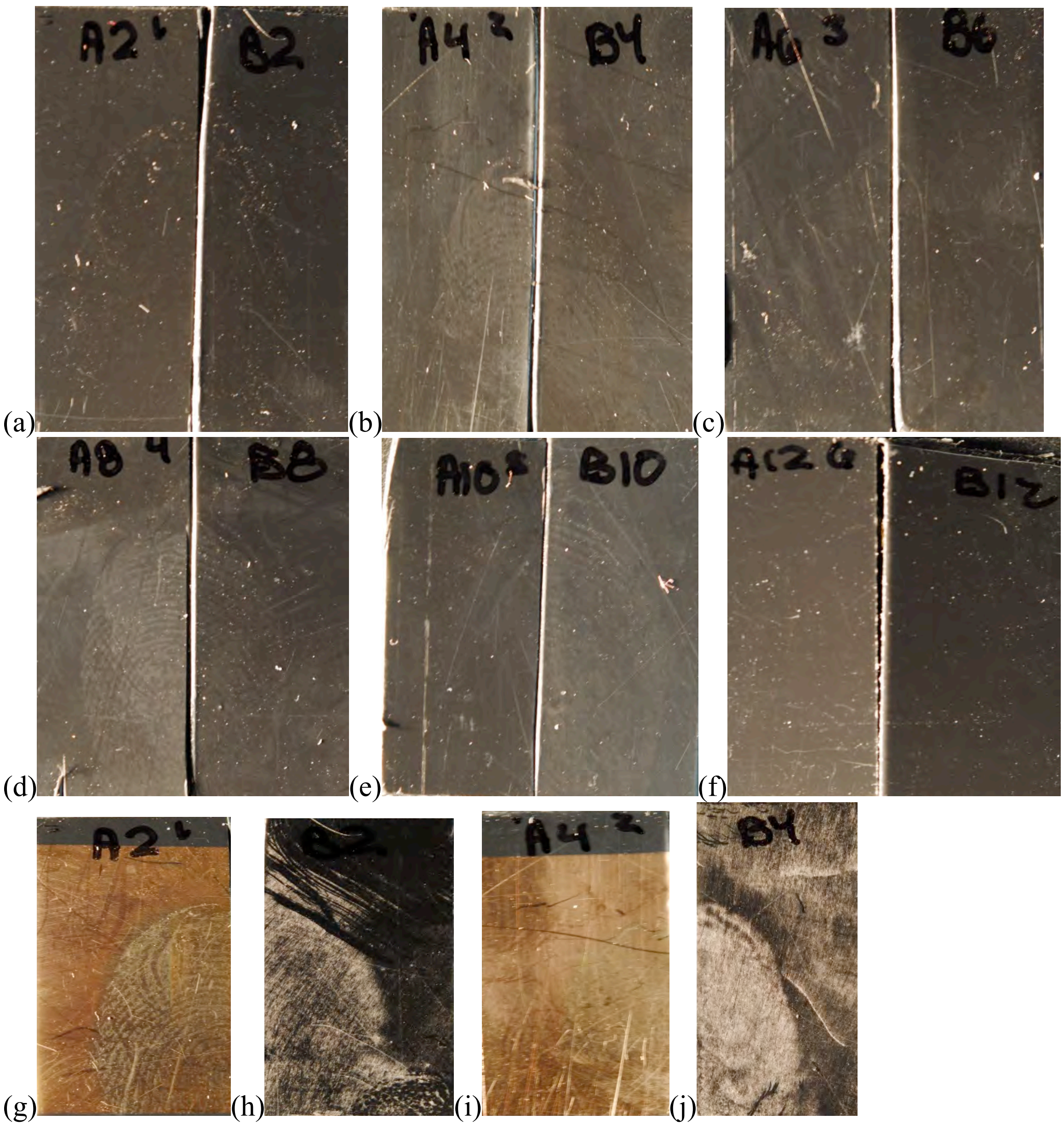


FIG. 17—Same as Fig. 16 except that the substrate is white nylon.



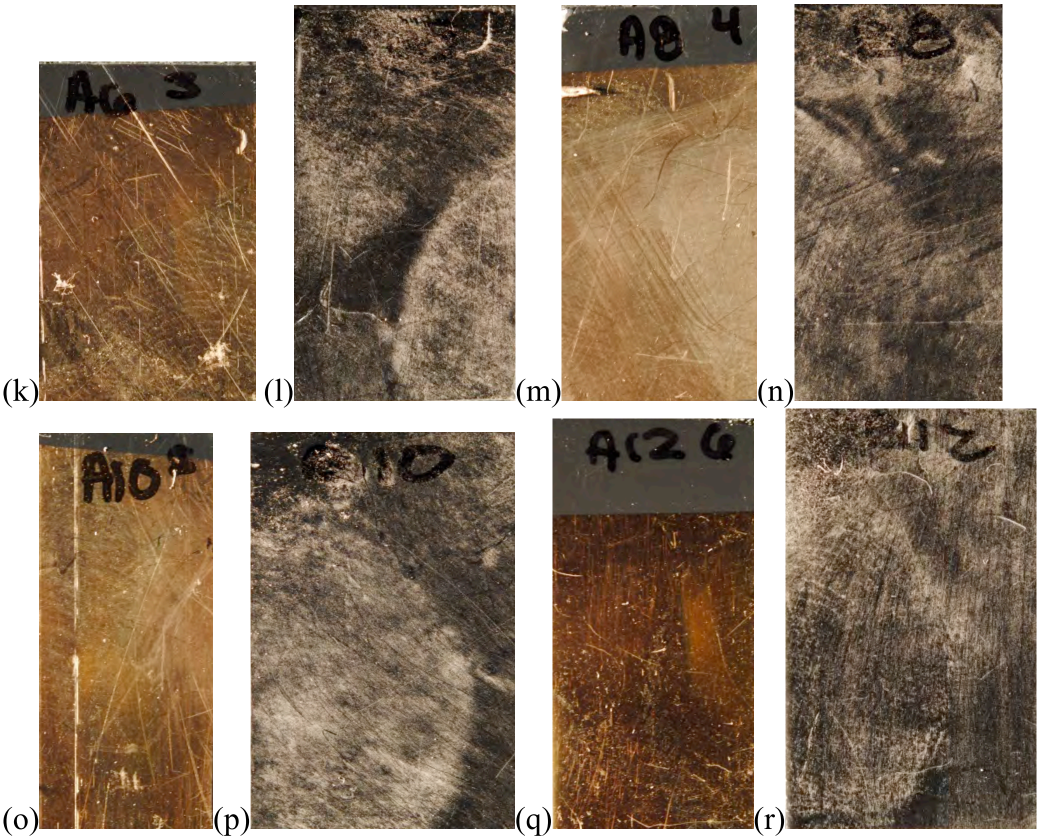


FIG. 18—(a-f) Images of the 2nd, 4th, 6th, 8th, 10th, and 12th members of a depleted fingerprint series on black ABS before development; (g,I,k,m,o,q) the same sequence of fingerprints developed with gold CTF; and (h,j,l,n,p,r) the same sequence of fingerprints developed by dusting with white powder.

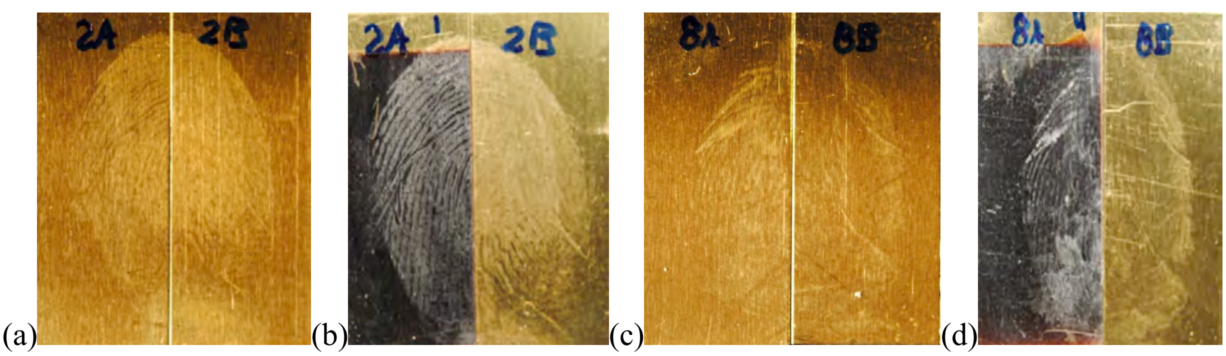


FIG. 19—(a) Second fingerprint in a depleted fingerprint series on brass before development, and (b) left side developed with chalcogenide-glass CTF and right side developed with cyanoacrylate fuming followed by dusting with black powder. (c) Eighth fingerprint in a depleted fingerprint series on brass before development, and (d) left side developed with chalcogenide-glass CTF and right side developed with cyanoacrylate fuming followed by dusting with black powder.

FIG. 20—Partial bloody fingerprint on 420-grade stainless steel developed either (left) by the use of cyanoacrylate fuming followed by dusting with regular black powder or (right) by the deposition of a 100-nm-thick CTF of nickel.

(a) (b) (c)

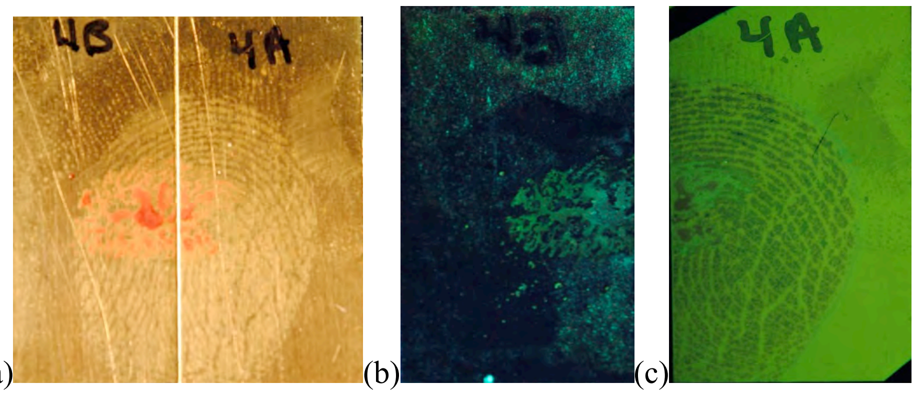


FIG. 21—(a) Partial blooody fingerprint on brass before development. (b) partial bloody fingerprint developed with fluoroscein and green fluorescent powder on brass, and (c) partial bloody fingerprint developed with Alq_3 on brass.

FIG. 22—Fingerprint on a bullet casing developed after discharge by a hybrid technique involving pretreatment of the latent fingerprint by cyanoacrylate fuming followed by the deposition of a 100-nm-thick CTF of Alq_3. Short-wave ultraviolet illumination is needed to see the detail.

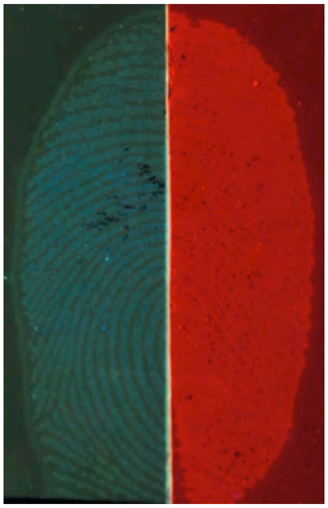


FIG. 23—Fingerprint on glass after the deposition of a CTF of (left) Alq_3 and (right) $Eu(tta)_3phen$.

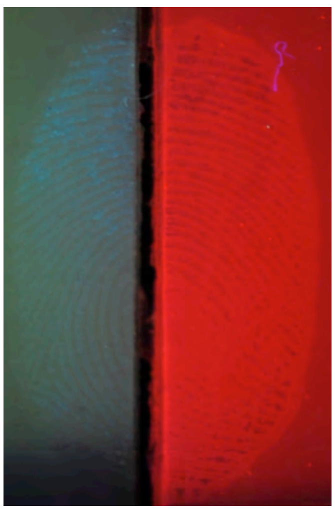


FIG. 24—Fingerprint on white nylon after the deposition of a CTF of (left) Alq_3 and (right) $Eu(tta)_3phen$.

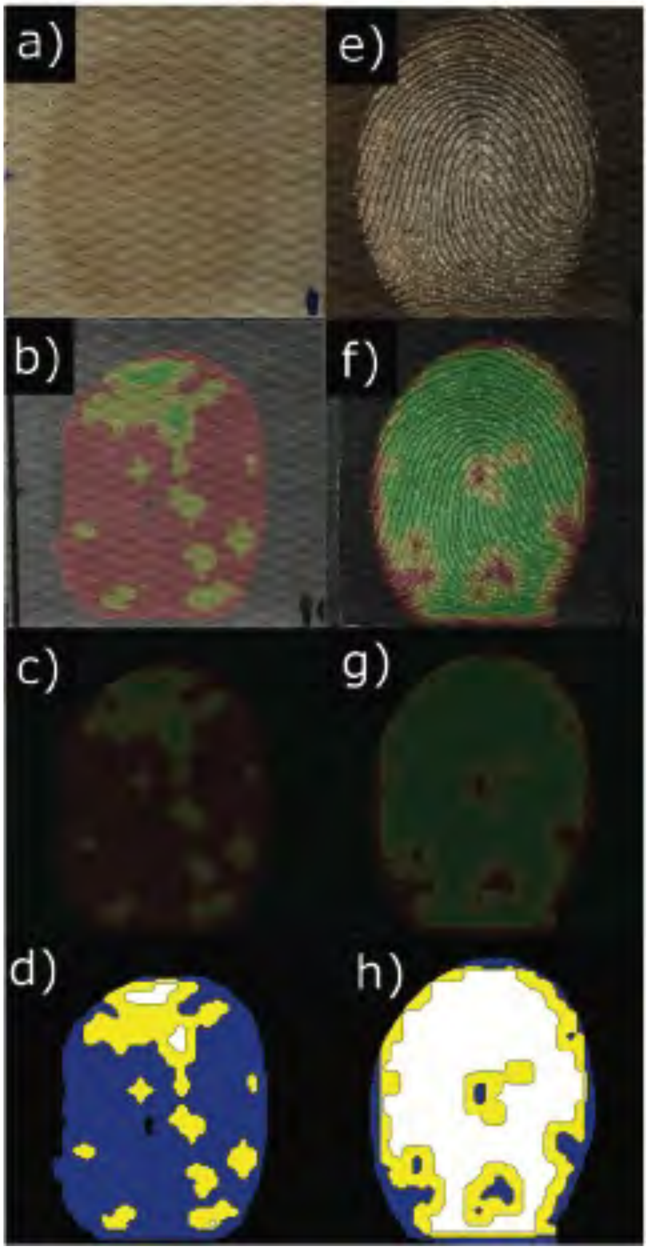


FIG. 25—(a) Latent fingerprint on Gorilla Tape® before development. (b) Same as (a) but with the raw quality map from ULW. (c) Same as (b) but with the quality map darkened prior to exporting. (d) Panel (c) after altering the colors in GIMP for input into Mathematica®. (e) Latent fingerprint on Gorilla Tape® after development with cyanoacrylate fuming. (f) Same as (e) but with the raw quality map from ULW. (g) Same as (f) but with the quality map darkened prior to exporting. (h) Panel (g) after altering the colors with GIMP for input into Mathematica®. Panels (d) and (h) correspond to 2.3% and 58% area of definitive minutiae, respectively; areas of definitive minutiae are indicated as white.

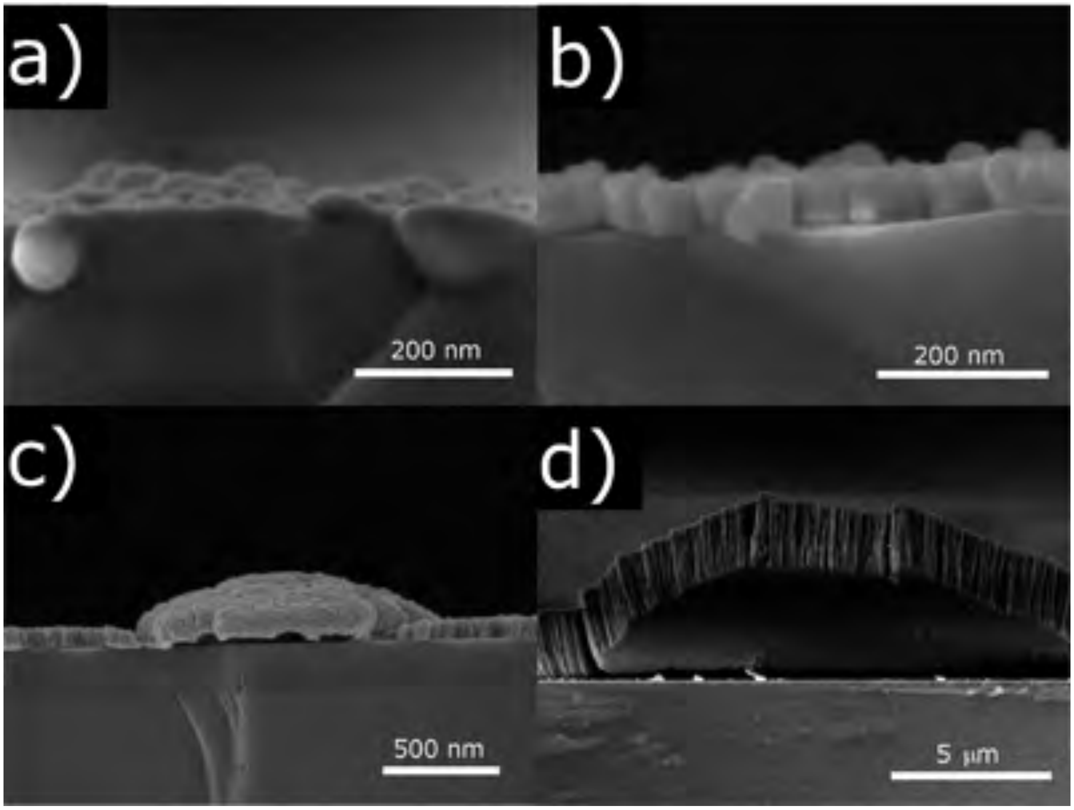


FIG. 26—Cross-sectional SEM images of (a) a zinc film deposited atop a gold film on a fingermarked silicon substrate by VMD, (b) a gold CTF deposited on a planar silicon substrate by the CTF technique, (c) a fingermark ridge on a silicon substrate conformally coated with a nickel CTF, and (d) a fingermark ridge on a glass slide conformally coated with a chalcogenide-glass CTF.

IV. Conclusions

IV.1. Discussion of findings

This research project was formulated to ascertain the optimum conditions for CTF development of latent sebaceous fingerprints on nonporous forensically relevant substrate. The CTFs were deposited using the CEFR technique. Once optimized, the CTF development method was to be compared with traditional development methods.

The results discussed in Section III.1 show that the optimization of CTF development of fingerprints on forensically relevant substrates was successful (Table 2). The results also show that for laboratory prepared fingerprints, without concern for sensitivity, the CTF development method is superior to traditional development techniques for some forensically relevant substrates, but for others, a traditional development technique produced a better outcome (Table 3). The results also show that traditional techniques and CTF were equally good for a few substrates (Table 3).

We also learned that examining and comparing results visually (subjectively) was not appropriate for this research because we needed a method that could assess the quality of developed fingerprints objectively so that we could effectively and fairly compare different development methods. Therefore, we devised a method using the FBI's ULW, an image manipulation software (GIMP) and a program developed in Mathematica® – in order to quantitate the minutae as a percentage (Section II.8). The method has the advantage of assessing not only the quality of individual fingerprints but also the relative performances of different development methods.

What this research showed was that, under laboratory conditions where sebaceous fingerprints were collected to ensure that sufficient fingerprint residue was deposited, CTF development was superior for several forensically relevant substrates but not for all. What this research did not demonstrate is the capability of CTF technique to develop aged or environmentally stressed fingerprints. Also, this research project did not comprehensively compare the CTF technique to a somewhat similar technique called VMD; while such a study was not envisaged as part of this project, a preliminary comparison was carried out (Sec. III.1.7).

In a study on depleted fingerprint series, we learned that CTF development of depleted fingerprints – to the 12^{th} fingerprint – is equal or superior to the traditional techniques we studied (Table 5).

After comparing the CTF development of partial bloody fingerprints with traditional development techniques, we found that the CTF technique is particularly useful for developing both the latent and patent areas of such fingerprints in just one development step (Tables 7 and 8).

Additionally, the research showed the potential usefulness of a hybrid technque where cyanoacrylate fuming and the CTF technique are used in tandem. The hybrid technique showed promise for discharged cartridge casings, though this was not an exhaustive study.

Finally, CTFs of two different fluorescent evaporant materials were found to be suitable for developing latent fingerprints on different substrates (Table 9).

It is likely that future research will show that CTF development of latent fingerprints is superior to traditional development techniques where the amount of fingerprint residue is limited and for fingerprints that are aged, degraded, or exposed to environmentally insulting conditions. Such outcomes may emerge, particularly when only a small amount of fingerprint residue is present because CTF development relies on the topology of the fingerprint rather than on some physical or chemical reaction with the fingerprint residue.

IV.2. Implications for policy and practice

Generally, the expected results were obtained, although not as all-encompassing with respect to substrates as originally thought. What is clear is that CTF development is a viable technique for developing latent fingerprints on difficult substrates. It provides investigators with a viable alternative to existing development techniques. And while the equipment is still laboratory-based, there is significant applicability to smaller items of evidence.

Since bloody fingerprints commonly occur at scenes, CTF development of small items containing partial bloody prints is particularly relevant because of the technique's ability to simultaneously develop the latent and patent aspects of the print. Also important may be the use of a hybrid technique – cyanoacrylate fuming followed by CTF development – on discharged cartridge casings. This is a difficult substrate on which to visualize latent fingerprints. The CTF technique shows significant promise, though.

Problems did occur, however. Highly textured substrates – e.g., textured duct tape – made it difficult to obtain results using the CTF technique. Additionally, problems were also encountered that occurred because a completely objective system for quantifying the quality of the fingerprints developed using the CTF technique and the traditional techniques and for comparing results of split fingerprints was needed. This was important because a subjective evaluation was considered inappropriate for deciding on the relative performances of the CTF technique and traditional development techniques.

Another problem involved the design and re-work of the low-pressure chamber to handle cartridge casings. The curved surface of the cartridge casing had to be taken into consideration when the CTF technique was employed to develop latent sebaceous fingerprints.

IV. 3. Implications for future research

Although the results of this research were largely successful, additional research is required in order for the CTF technique to become a routine law enforcement tool. The specific areas that require further work follow.

- Comprehensive comparison of the CTF technique with VMD. Since both techniques are similar, a side-by-side comparison is necessary. The CTF technique specifically considers development on curved surfaces and also because it deposits a thin film on the ridges of the fingerprint compared with VMD that deposits gold in the fingerprint residue followed by zinc deposition in the areas outside of the ridges.
- This research was conducted on ideal, laboratory-prepared, sebaceous-only fingerprints

that were aged 24 hours. This work needs to be extended to include more reality based fingerprints – i.e., fingerprints exposed to various environmental insults (heat, humidity and aging).

- The hybrid technique of cyanoacrylate fuming followed by CTF development of fingerprints shows great promise having application to a wide range of forensically relevant substrates, specifically discharged cartridge casings.
- The nature of CTF deposition will allow investigators to ascertain the sequential development of fingerprints – which was deposited first?
- Guidelines need to be developed for specific substrates so that investigators can optimize CTF development of latent fingerprints by selectively choosing the appropriate evaporants for a specific substrate.
- Field-forward CTF development equipment is needed. The results of this research suggest parameters for such a design that would include simultaneous development on multiple items coupled with cyanoacrylate fuming, if necessary.

V. References

1. Humphries J, Porter G, Bell M. The quantification of fingerprint quality using a relative contrast index. Forensic Sci. Int. 2008;178:46-53. Fronthaler H, Kollreider K, Bigun J. Automatic image quality assessment with application in biometrics. IEEE Conference on Computer Vision and Pattern Recognition Workshop. Volume 2. 2006: June 17-22, pp. 30-37. Tabassi E, Wilson CL. A novel approach to fingerprint image quality. IEEE Conference on Computer Vision and Pattern Recognition Workshop. Volume 2. 2005: Sept 11-14, pp. II 37-40. Sears VG, Bleay SM, Bandey HL, Bowman VJ. A methodology for finger mark research. Science Justice 2012;2:145-60.

2. Lakhtakia A, Shaler RC, Martín-Palma RJ, Motyka MA, Pulsifer DP. Solid-state acquisition of fingermark topology using dense columnar thin films. J. Forensic Sci. 2011;56:612-6.

3. Martín-Palma RJ, Pantano CG, Lakhtakia A. Replication of fly eyes by the conformal evaporated-film-by-rotation technique. Nanotechnology 2008;19:355704.

4. Martín-Palma RJ, Pantano CG, Lakhtakia A. Biomimetization of butterfly wings by the conformal-evaporated-film-by-rotation technique for photonics. Appl. Phys. Lett. 2008;93:083901.

5. Martín-Palma RJ, Pantano CG, Lakhtakia A. Towards the use of the conformal evaporated-film-by-rotation technique in fabricating microelectronic circuits and microsystems. Microelectron. Rel. 2009;49:460-2.

6. Pulsifer DP, Lakhtakia A, Martin-Palma RJ. Improved conformal coatings by oblique-angle deposition for bioreplication. Appl. Phys. Lett. 2009;95:193701.

7. Mattox DM. The foundations of vacuum coating technology. Norwich, NY, USA: Noyes Publications, 2003.

8. Lakhtakia A, Messier R. Sculptured thin films: nanoengineered morphology and optics.Bellingham, WA, USA: SPIE Press, 2005.

9. National Research Council. Summary: Findings and Recommendations. In: Strengthening Forensic Science in the United States A Path Forward. The National Academies Press. 2009:14-33.

10. Ramotowski RS. Chapter 3: Composition of Latent Fingerprint Residue. In Advances in Fingerprint Technology 2nd Edition. Eds. Lee RC and Gaensslen RE. CRC Press, 2001 pp. 63-104.

11. Champod C, Lennard C, Margot P, Stoilovic M. Chapter 4: Fingerprint detection techniques. In: Fingerprints and Other Ridge Skin Impressions, CRC Press. 2004.

12. Lee HC and Gaensslen RE. Chapter 4: Methods of latent fingerprint development. In Advances in Fingerprint Technology 2nd Edition. Eds. Lee RC and Gaensslen RE. CRC Press, 2001 pp. 105-75.

13. Almog J, Azoury M, Elmaliah Y, Berenstein L, Zaban A. Fingerprints' third dimension: The

depth and shape of fingerprints penetration into paper – cross section examination by fluorescence microscopy. J. Forensic Sci. 2004;49:1-5.

14. Migron Y, Mandler D. Development of latent fingerprints on unfired cartridges by palladium deposition: A surface study. J. Forensic Sci. 1997;42:986-92.

15. Watkin JE, Wilkinson D, Misner AG, Yamashita AB. Cyanoacrylate fuming of latent prints: vacuum versus heat/humidity. J. Forensic Ident. 1994;44:545-56.

16. Jones N, Mansour D, Stoilovic M, Lennard C, Roux C. The influence of polymer type, print donor and age on the quality of fingerprints developed on plastic substrates using vacuum metal deposition. Forensic Sci. Int. 2001;124:167-77.

17. Kent T, Thomas GL, Reynoldson TE, East HW. A vacuum coating technique for the development of latent fingerprints on polythene. J. Forensic Sci. Soc. 1976;16:93-101.

18. Home Office Scientific Development Branch. Additional Fingerprint Development Techniques for Adhesive Tapes. 2006. Publication No. 23/06.

19. Bond J. Visualization of latent fingerprint corrosion of metallic surfaces. J. Forensic Sci. 2008:53:812-22.

20. Bond J. The thermodynamics of latent fingerprint corrosion of metal elements and alloys. J. Forensic Sci. 2008;53:1344-52.

21. Cantu AA, Leben DA, Ramotowski R, Kopera J, Simms JR. Use of acidified hydrogen peroxide to remove excess gun blue-treated cartridge cases and to develop latent prints on untreated cartridge cases. J. Forensic Sci. 1997;42:294-8.

22. Wargacki SP, Lewis LA, and Dadmun MD. Enhancing the quality of aged latent fingerprints developed by superglue fuming: Loss and replenishment of initiator. J. Forensic Sci. 2008;53:1138-44.

23. Sears V, Colin G, Butcher PG, Fitzgerald LA. Enhancements of fingerprints in blood Part 3: Reactive techniques, Acid Yellow 7 and process sequences. J. Forensic Ident. 2005;55:741-63.

24. Kundt A. Ueber Doppelbrechung des Lichtes in Metallschichten, welche durch Zerstäuben einer Kathode hergestellt sind. Ann. Phys. Chem. Lpz. 1886;27:59-71.

25. Baumeister, P. W. Optical coating technology. Chap. 9. Bellingham, WA, USA: SPIE Press, 2004.

26. Yang B, Walden BL, Messier R, White WB. Computer simulation of the cross-sectional morphology of thin films. Proc. SPIE 1987;821:68-76.

27. http://www.alibaba.com/product/jpvaras-105042162-101267446/Pin%20Point%20Impression%20Toy.html.

28. http://www.gimp.org

29. http://www.wolfram.com

30. Migron Y, Hocherman G, Springer S, Almog J, Mandler D. Visualization of sebaceous fingerprints on fired cartridge cases: A laboratory study. J Forensic Sci 1998;43:543-8.

VI. Dissemination of Research Findings

- Publications, conference papers, presentations:

1. S.A. Muhlberger, D.P. Pulsifer, A. Lakhtakia & R.C. Shaler, "Optimized deposition of columnar thin films for visualization of latent fingerprints," *Nanoelectronic Devices for Defense & Security Conference*, Polytechnic Institute of New York University, Brooklyn, NY, USA, August 29–September 1, 2011.

2. S.A. Muhlberger, D.P. Pulsifer, R.J. Martín-Palma, R.C. Shaler & A. Lakhtakia, "Optimized deposition of columnar thin films for visualization of latent fingerprints," *39th Annual Symposium of American Society of Crime Laboratory Directors*, Denver, CO, USA, September 18–22, 2011 (Poster).

3. D.P. Pulsifer, S.A. Muhlberger, R.J. Martín-Palma, R.C. Shaler & A. Lakhtakia, "Optimal conditions for visualization of fingerprints with the conformal-evaporated-film-by-rotation technique," *58th Annual International Symposium of American Vacuum Society*, Nashville, TN, USA, October 30–November 4, 2011.

4. S. Muhlberger, R. Shaler, A. Lakhtakia, D. Pulsifer, & R. Martín-Palma, "Visualization of latent fingerprints using columnar thin films," *64th Annual Scientific Meeting of American Academy of Forensic Sciences*, Atlanta, GA, USA, February 20–25, 2012.

5. S.F. Williams, R. Shaler, D.P. Pulsifer & A. Lakhtakia, "Visualizing latent fingerprints using columnar thin films," *2012 Annual Meeting of North East Association of Forensic Scientists*, Saratoga Springs, NY, USA, October 12–17, 2012.

6. S.F. Williams, R. Shaler, D. Pulsifer, & A. Lakhtakia, "Visualization of depleted latent fingerprints using columnar thin films," *65th Annual Scientific Meeting of American Academy of Forensic Sciences*, Washington, DC, USA, February 18–23, 2013.

7. S.A. Muhlberger, D.P. Pulsifer, A. Lakhtakia, R.J. Martín-Palma & R.C. Shaler, "Optimized development of sebaceous latent fingermarks on non-porous substrates with conformal columnar thin films," *Journal of Forensic Sciences*; accepted for publication.

8. D.P. Pulsifer, S.A. Muhlberger, S.F. Williams, R.C. Shaler & A. Lakhtakia, "An objective fingerprint quality grading system," *Forensic Science International*, Vol. 231, pp. 204–207 (2013).

9. S.F. Williams, D.P. Pulsifer, A. Lakhtakia & R.C. Shaler, "Columnar-thin-film-assisted visualization of depleted latent sebaceous fingermarks on nonporous metals and hard plastics," *Journal of Forensic Sciences*; currently under review for publication.

10. S.F. Williams, D.P. Pulsifer, R. C. Shaler & A. Lakhtakia, “Visualization of partial bloody fingermarks on nonporous substrates using columnar thin films,” *Forensic Science International*; currently under review for publication.

- Websites: Nothing to report