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PAPER

CRIMINALISTICS

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Solid-State Acquisition of Fingermark Topology using Dense Columnar Thin Films

ABSTRACT: Various vacuum techniques are employed to develop fingermarks on evidentiary items. In this work, a vacuum was used to deposit columnar thin films (CTFs) on untreated, cyanoacrylate-fumed or dusted fingermarks on a limited selection of nonporous surfaces (microscope glass slides and evidence tape). CTF deposition was not attempted on fingermarks deposited on porous surfaces. The fingermarks were placed in a vacuum chamber with the fingermark side facing an evaporating source boat containing either chalcogenide glass or MgF_2. Thermal evaporation of chalcogenide glass or MgF_2 under a 1 μTorr vacuum for 30 min formed dense CTFs on fingermark ridges, capturing the topographical features. The results show that it is possible to capture fingermark topology using CTFs on selected untreated, vacuumed cyanoacrylate-fumed or black powder–dusted nonporous surfaces. Additionally, the results suggested this might be a mechanism to help elucidate the sequence of deposition.

KEYWORDS: forensic science, fingermarks, columnar thin films, impression evidence, fingermark topology, solid-state acquisition

The premise of our work is that physical vapor deposition (PVD) may be applicable to fingermark development. For over a hundred years, columnar thin films (CTFs) of solid materials have been deposited as coatings (1,2) for optical, magnetic, electrical, tribological, and other purposes (3). CTFs are assemblies of parallel, straight columns or nanowires. Typically, as a CTF is grown on a planar substrate mounted on a platform, the tops of the columns together constitute a surface that is almost planar. When the substrate has a slight undulation, possibly because of 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 (4). Consequently, if a CTF were to be deposited on a fingermark, the top surface of the CTF would be expected to reproduce the topological details of the fingermark. The resulting acquired mark could then be visualized using optical techniques—oblique lighting and close-up photography—hopefully obviating, though not necessarily precluding, the need for subsequent chemical or other physical development methods.

The concept behind the proposed solid-state acquisition of fingermark topology can be explained by comparing it to a child's toy called the Pin Point Impression (5). This toy is a dense collection of parallel, identical, thin 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). When the pins stand over an undulating surface, one with topology, the pin heads also form an undulating surface (Fig. 1, right), 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 surface by the pin head top surface. If the pins of the toy could be glued together, they would "store" the features of the substrate.

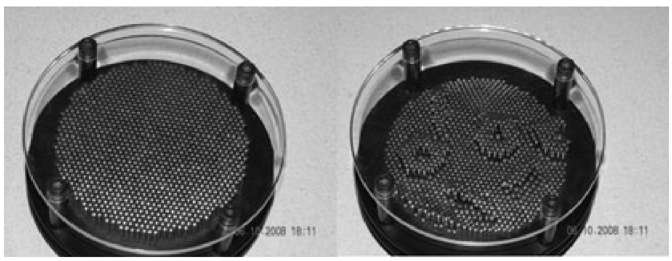

FIG. 1—*Illustration of the concept using a toy called Pin Point Impression comprising parallel, identical, thin cylindrical pins. Left panel: pins over a flat surface. Right panel: pins over an undulating surface.*

The Pin Point Impression toy is analogous to the morphology of CTFs whose growth occurs by thermal evaporation (3). At a pressure of around 1 μTorr, material (chalcogenide glass and MgF_2 used in this work) in a source boat is electrically heated to evaporate upward toward a planar substrate (fingermark), as shown in Fig. 2. The fingermark faces the source boat allowing the evaporating material to settle on it, 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, in this case, the fingermark residue. These clusters evolve into expanding and competing columns as the film thickness increases, as has been reviewed elsewhere (3).

Of the other PVD techniques available, thermal evaporation is the simplest and gentlest for growing CTFs (3) because the substrate is not adversely impacted by the impinging atoms and molecules traveling with high momentums, a significant criterion for the

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high-fidelity replication of a fingermark. Furthermore, a significantly large and in-depth understanding of thermal evaporation exists in the scientific community as do several variations of this technique to achieve high-density CTFs (6,7). A recent variation is the conformal-evaporated-film-by-rotation (CEFR) technique, which has been used to develop CTF replicas on templates having micro- and nano-scale features distributed over planar as well as curved surfaces such as the eyes of flies and wings of butterflies (8,9), making this technique suitable for the solid-state acquisition of fingermark topology. To our knowledge, CTFs have never been consciously deposited on substrates with fingermarks.

For this work, the formation of a CTF was used to capture fingermark topology, a technique fundamentally different from other vacuum fingermark development techniques, such as vacuum metal deposition (VMD) (10,11). In the usual VMD technique, gold is first evaporated in vacuum to form a thin layer on the exposed surface, with the gold layer penetrating the fingermark emulsion. Next, a layer of zinc or cadmium is deposited in the same manner. This second layer lies atop the gold layer but does not penetrate the fingermark emulsion. This leaves the fingermark ridges transparent while the zinc/cadmium background is dark (12). In contrast, the CTF forms a conformal coating on the fingermark ridge, thus mapping the topography of the fingermark.

Materials and Methods

Three different sets of fingermark topography were acquired using CEFR. For set #1, a sebaceous fingermark was deposited on a clean glass microscope slide. For set #2, three sebaceous fingermarks were deposited sequentially on a clean glass slide. Set #3 comprised two items: (i) a glass slide with three fingermarks and (ii) another glass slide covered with evidence tape on which two fingermarks, not visible, were deposited. Item (i) in set #3 was prepared in the following steps. A sebaceous fingermark was placed on a clean glass microscope slide on the left side of the slide, and the area of the slide without fingermarks was covered with evidence tape. The glass slide was vacuum-superglue-fumed (1 atm pressure, 0.0% relative humidity) for 30 min. The fumed prints were visually observable, although no photographs were taken. After superglue-fuming, the tape was removed and a second sebaceous fingermark was placed in the middle of the glass slide next to the fumed print. The second print was dusted carefully with black dusting powder so as not to contaminate the superglue-fumed print. Before dusting, the blank area of the slide was covered again with the evidence tape. After dusting, the evidence tape was removed and a third sebaceous fingermark was placed to the right of the dusted fingermark, the right side of the slide, and left untreated. All manipulations of the glass slide and the evidence tape were made purposely without wearing latex gloves. The glass slide and the evidence tape were subjected to CTF development on both surfaces.

The CTFs for sets #1 and #3 were made of chalcogenide glass having a nominal composition of $Ge_{28}Sb_{12}Se_{60}$. Although chalcogenide glass is a commonly employed deposition substance, the CTF for set #2 was made using MgF_2 to ascertain whether another commonly used deposition substance might also be applicable. These materials are commonly used because of their good mechanical properties.

The chalcogenide glass placed in a tungsten boat in the vacuum chamber was heated by passing a 95-A current through the boat, whereas a current of 70 A was passed when MgF_2 was evaporated from a narrower boat. For all three sets, the vapor flux was directed very obliquely—at 5° (chalcogenide glass) and 10° (MgF_2) to the substrate plane containing the fingermarks while the substrate was rotated at 30 rpm about an axis passing normally through its centroid. All three deposition processes were carried out at a nominal pressure of 1 μTorr for 30 min, resulting in a conformal coating of thickness around 550 nm (chalcogenide glass) and 350 nm (magnesium fluoride) grown onto the fingermarks, as measured by a quartz crystal monitor.

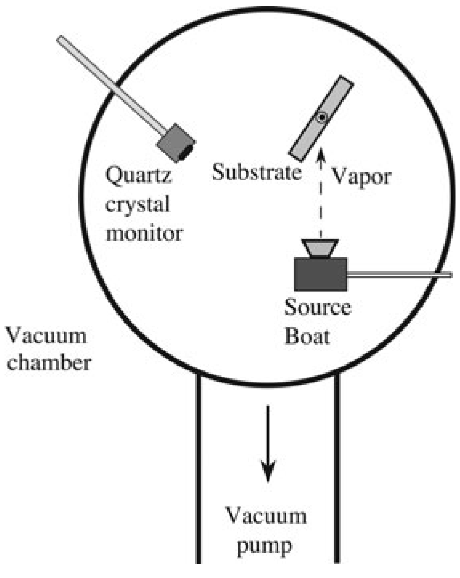

FIG. 2—*Schematic of the chamber to grow columnar thin films by thermal evaporation.*

Results and Discussion

Sets #1 and 2 were targeted to establish a proof of the concept underlying the solid-state acquisition technique. The left side of Fig. 3 shows an optical image (highlighted by oblique lighting and close-up photography) of a chalcogenide-glass CTF grown on a sebaceous fingermark deposited on a glass slide. Because the chalcogenide is dark colored and does not show well on the computer monitor, the photographed image was enhanced using the gamma, color, and contrast functions in Windows Picture and Fax Viewer software (Microsoft Corp., Redmond, WA). The fingermark ridges are evident in the SEM (75×) image in Fig. 4, such that where no fingermark residue was deposited, no texture is apparent. A close inspection of the tops of the ridge detail in Fig. 4 suggests columnar formation, but higher magnification is necessary to more clearly

FIG. 3—*Set #1. Left panel: optical photograph of a chalcogenide-glass columnar thin film grown on top of a glass slide with a sebaceous fingerprint. Right panel: the same photograph after software enhancement.*

discern the detail. An SEM image (10,000×) of a ridge in the image of Fig. 3 shows the tops of the CTF columns (Fig. 5), illustrating that the evaporating chalcogenide did not simply cover the ridges as a smooth film.

Energy-dispersive X-ray (EDX) analysis of the CTF deposited on the fingermark ridge in Fig. 3 was carried out next to show that the fingermark residue remains amenable to chemical analysis after CTF formation. The result is presented in Fig. 6, showing the elements present in the developed fingermark: Au, C, Ca, Cl, Ge, K, Na, O, Sb, Se, and Si. Certainly, Ge, Sb, and Se are present because of their occurrence in chalcogenide glass. Gold provided high electrical conductivity for the subsequent SEM characterization. The chalcogenide glass could also contain traces of oxides of silicon, sodium, calcium, magnesium, potassium, and aluminum. Importantly, though, the high peaks in the EDX spectrum of carbon and chloride are present in the fingermark residue and are not constituents of the chalcogenide CTF, which means that the fingermark residue, although entombed under the CTF, might be amenable to subsequent fingermark development techniques.

Set #2 comprised three fingermarks deposited on a glass slide, on which a CTF of MgF_2 was deposited using the CEFR technique. An optical image of the postdeposition sample is presented in Fig. 7. Software enhancement was not necessary to more clearly see the image, such as was used for the chalcogenide CTF in Fig. 3, because the MgF_2 CTF was clearly visible using oblique lighting.

Set #3 comprises two items. The first has three fingermarks on a glass microscope slide and the second on evidence tape. For the first, fingermarks were deliberately placed on a glass slide in sequence, and a chalcogenide-glass CTF formed on top of the marks. The superglue-fumed mark—labeled 1 in Fig. 8 (top)—shows a CTF layer and ridge detail. To the left of the number "1" as well as lower and left of the full print, two extraneous fingermarks are visible, which were also cyanoacrylate-fumed and then developed using the CTF growth process. These results illustrate CTF formation can occur over a previously superglue-fumed print which can then be visualized without subsequent chemical staining or powder-based development. This is not unexpected as cyanoacrylate polymerization on fingermark ridges forms a "crust" that itself has topological features. The result also shows that CTF growth can occur on the nonsticky side of at least one type of tape.

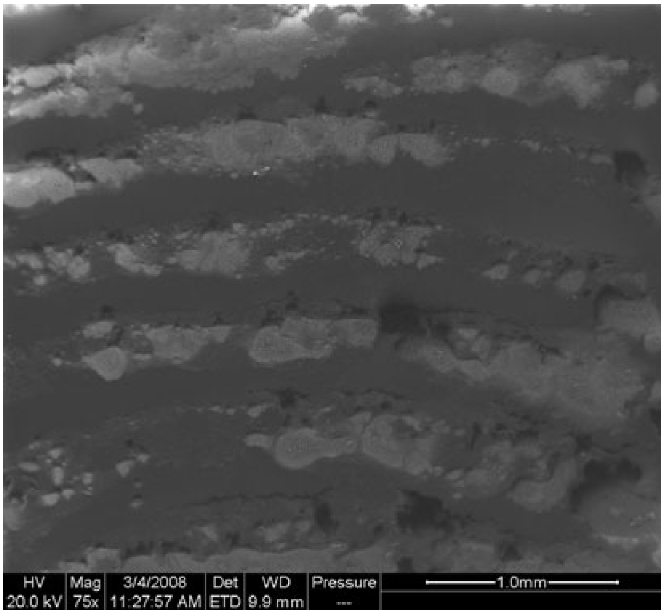

FIG. 4—*Set #1. Top-surface SEM image (75×) of a chalcogenide-glass columnar thin film grown on top of a glass slide with a sebaceous fingermark.*

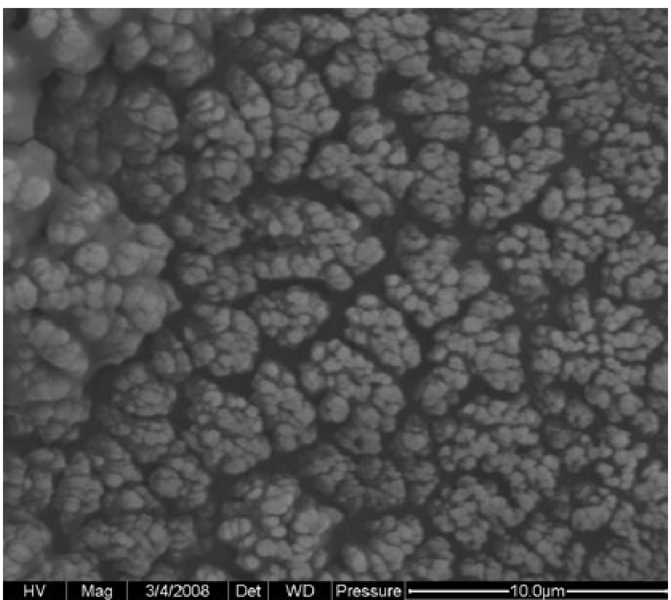

FIG. 5—*Set #1: same as Fig. 3, but the magnification is 10,000×.*

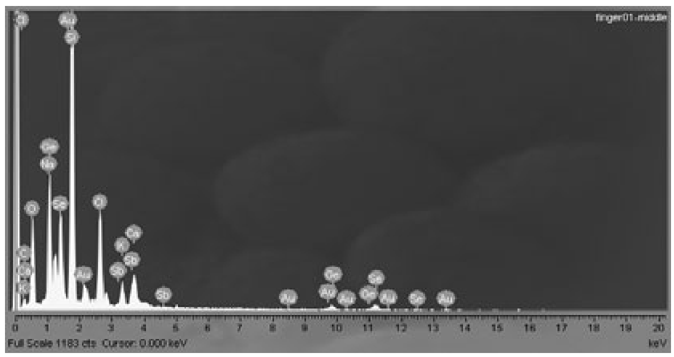

FIG. 6—*Set #1. Energy-dispersive X-ray spectrum of a chalcogenide-glass columnar thin film grown on top of a glass slide with a sebaceous fingerprint.*

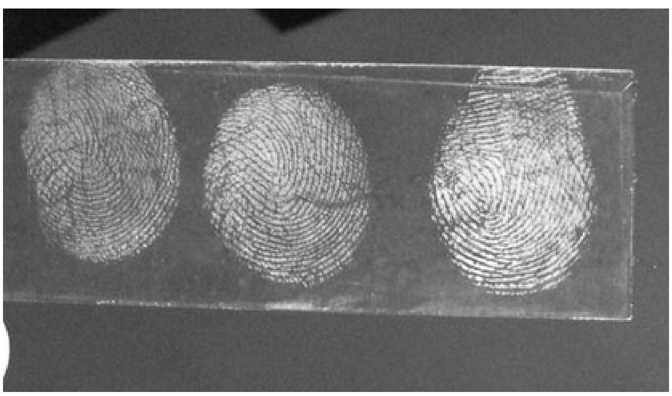

FIG. 7—*Set #2. Optical photograph of a MgF_2 columnar thin film deposited on three sebaceous latent fingerprints placed on a glass microscope slide.*

FIG. 8—*Set #3 comprising two items. Top panel: optical image of the first item. Bottom panel: optical image of the second item.*

FIG. 9—*Cropped image from the middle print in the first item of set #3 showing overlapping prints.*

The middle fingermark in Fig. 8 (top) was dusted with black dusting powder before CTF formation. To the left of this is another "unintentionally deposited" fingermark visible to the left of the full fingermark and partly covered by the number "2." It, too, was cyanoacrylate-fumed. A closer inspection of the image suggests that it was deposited before the full fingermark: although the focus is not perfect, it appears from Fig. 9 that the larger, full middle fingermark in Fig. 8 (top) sits on top of the partial fingermark to its left. Although the clarity is not sufficient to make a definitive statement with respect to the sequence of these marks, these data suggest that CTF formation might help examiners ascertain the fingermark deposition sequence; however, further work is necessary.

The third fingermark in the first item of set #3, far right in Fig. 8 (top), was untreated. The resulting CTF shows ridge detail. The actual color of the developed fingermarks is the same color as the chalcogenide glass, which is brownish.

The second item in set #3 (Fig. 8, bottom), comprises two fingermarks placed on evidence tape used to cover the glass slide during manipulations of the fumed and dusted fingermarks in the first item. The evidence tape was handled without latex gloves purposely to see whether CTF formation would occur on a piece of tape. The photograph in Fig. 8 (bottom) shows several CTF developed fingermarks.

Conclusions

Although the results of this research show that it is possible to capture the surface topology of nascent fingermark residue, the extent of the forensic applicability of CTF formation to fingermark development is not known. Two different, single evaporants were used to demonstrate the concept. Although CTFs of both evaporants, chalcogenide glass (on glass and evidence tape) and MgF_2 (on glass), grew on fingermark residue, neither the optimum CTF print development conditions (most appropriate vacuum conditions, optimal angle of the evaporant flux with respect to the substrate, etc.) nor the most appropriate evaporants constituted a part of this work.

A priori one might expect that CTF-captured topology of fumed marks would mimic the underlying structure of the polycyanoacrylate even though fingermarks formed under vacuum have different physical characteristics than those formed using heat in a humid environment, the former being smoother than the latter (13). The results in Fig. 9 demonstrated CTFs can form over vacuum-cyanoacrylate-fumed fingermarks, suggesting that CTF formation might be an alternative to chemical staining or powder dusting for visualizing fumed marks.

Certainly, the observations described in this work suggest a need for continued research. First, the density of the fingermark residue dictates the "thickness" of the captured ridge detail, which is related to the relative amount of sebaceous secretions present in various areas of the print or on how the mark was deposited; those areas having less sebaceous secretions show weaker detail, weak marks in Fig. 8 (bottom) on the evidence tape, while those areas having denser secretions show denser detail (Fig. 8, top—rightmost mark). This is not unexpected as fingermark density varies from one area to another. However, there was no attempt to control how the CTF formed over various areas of the fingermark, and it is unknown whether CTF deposition can be controlled so precisely.

Second, CTF fingermarks were developed on a limited selection of nonporous surfaces and the range of substrates amenable to CTF fingermark development is unknown. Also, so-called clean prints, those not having sebaceous residue, may not have sufficient surface topology on which to grow CTFs. This has not been tested, but one might argue that the eccrine reside should have a topological structure.

Third, from studying Fig. 9, it is tempting to consider CTF formation as a mechanism to decipher the sequence of overlapping prints. In this regard, though, a systematic investigation was not performed.

Limitations of the procedure include the expense of the equipment, as special vacuum conditions are required, and the size of the vacuum chamber, which limits the size of items that fit inside the chamber. Neither the precise vacuum conditions for CTF formation on fingermarks nor the design of the vacuum chamber were subjects of this research.

Finally, fingermarks constitute but one example of a class of evidence called impression evidence, which generally has a textured topology. Most impression evidence includes items larger than the vacuum chamber employed used in this study, but other examples are smaller, e.g., bullets and cartridge cases, and they would fit inside the chamber.

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