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E. J. Korda

H. L. MacDonell

J. P. Williams

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FORENSIC APPLICATIONS OF THE SCANNING ELECTRON MICROSCOPE*

E. J. KORDA, H. L. MACDONELL AND J. P. WILLIAMS

E. J. Korda is a Research Scientist, Instrumental Analysis, Corning Glass Works, Corning, New York. He was an Associate Professor of Metallurgy at the Drexel Institute of Technology, Philadelphia, and Director of their Electron Microscopy Laboratory.

H. L. MacDonell is a Research Chemist, Corning Glass Works and a Consulting Criminalist. Mr. MacDonell has previously served as a Forensic Scientist at the Rhode Island State Crime Laboratory and has taught police science courses at the Corning Community College. He is a fellow of the American Academy of Forensic Sciences and a member of the Canadian Society of Forensic Sciences. His publications have appeared in a number of professional journals.

J. P. Williams, Ph.D. is Manager of the Instrumental Analysis Research at the Research and Development Laboratories, Corning Glass Works. He has worked in the area of chemical and instrumental analysis at Corning since 1950.—EDITOR.

The physical sciences have long been utilized by those concerned with law enforcement. Chemical analysis, for example, has always been an essential portion of toxicology. In 1832 Coley published the book *Poisons and Asphyxia* containing the chemical analysis procedures of that period. (1) Bertillon developed a system of anthropometric measurements in 1882 which permitted the classification of prisoners. (2) Though the system was useful, it was not infallible and finally yielded to the more accurate and practical system of fingerprint identification. (3, 4) Likewise, with improvements in firearms and ammunition there followed advances in firearms identification using characteristics not possible with earlier cap and ball smoothbore weapons.

During the past fifty years a few dedicated pioneers in scientific crime investigation have slowly incorporated more science into police science. As a result, a new discipline known as criminalistics has evolved which is primarily concerned with physical evidence and the use of science in its examination. It is both logical and unfortunate that considerable time is often required before developments in methodology and/or instrumentation reach their ultimate utilization. Frequently, an instrument is available that may solve a particular problem, and yet its application to the problem may go unnoticed for many years. The objective of this paper is to present some of the possible applications of scanning electron microscopy (SEM) to the field of criminalistics and thus to suggest expanded use of this new microscope for forensic purposes.

The SEM has evolved from the work of a number of scientists over the past 30 or more years. (5) The first commercial instrument, which became available in 1965, was based primarily on the activities of a group at the University of Cambridge under the direction of Oatley. (6) A schematic drawing of the SEM is shown in Figure 1. A beam of electrons is generated by a tungsten

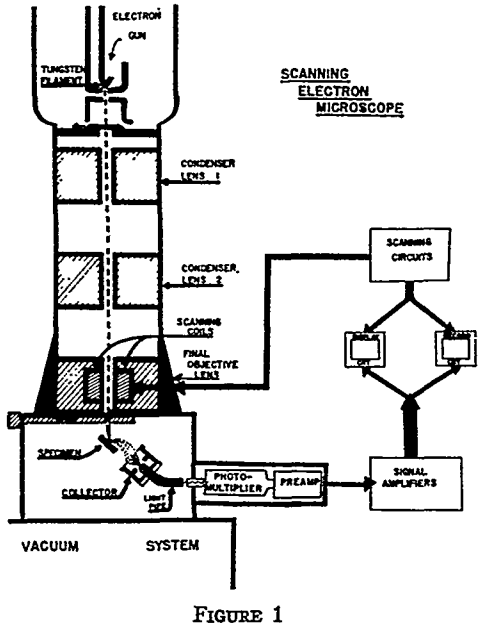

FIGURE 1
Schematic Drawing of SEM.

*Portions of this paper were presented by Dr. Williams during the Symposium on Forensic Chemistry, American Chemical Society, 156th National Meeting held in Atlantic City, New Jersey, Wednesday 11, September 1968. Mr. MacDonell was Chairman of the Symposium.

TABLE 1

COMPARISON OF OPTICAL, SCANNING, AND TRANSMISSION ELECTRON MICROSCOPY

Comparison Factors	Optical Microscopy	Scanning Electron Microscopy	Transmission Electron Microscopy
Magnification Range	1 to 1200×	50 to 30,000×	500 to 250,000×
Resolution Possible	2,000 Å	150 to 200 Å	<5 to 50 Å
Relative Depth of Focus	1	300	
Type of Observation	Direct	Direct	Mainly Replica Direct Difficult
Sample Preparation Time	Minutes to hours	Minutes	Hours to Days
Other Modes	IR, UV	Luminescent & Conductive	Electron Diffraction

filament and demagnified by three electromagnetic lenses to a spot size of about 100 Å. The accelerating voltage for the electrons can be varied from 1 to 20 kv. When the primary beam strikes the specimen, the energy is converted to heat, light, X-rays, back-scattered electron reflections, and secondary electron emission. In the SEM emissive mode the secondary electrons are collected from each point and integrated into a total image on a cathode ray tube (CRT) which scans visually in synchronism with the primary beam. Magnification is achieved by the relationship of the area on the specimen scanned by the primary beam and the area pictured on the CRT.

The energy range of the secondary electrons is low, in the order of 6 to 50 ev, and accordingly the secondaries can be drawn in curved trajectories by a small positive bias to a collector-detector system consisting of a focusing electrode, scintillator, light pipe, and photomultiplier. The ability to select and detect the secondary electrons in this manner, coupled with the fact that they are being generated at a very fine spot on the surface of the specimen, makes the emissive mode of the SEM a superior means to examine surface topography directly with great resolution and depth of focus. A comparison of the characteristics of optical, scanning, and transmission electron microscopy is summarized in table 1.

Specimen preparation for SEM observation is minimal. Electrical conductors, such as metals, can be studied directly. Insulators, which include organic materials, require a thin conducting coating. A recommended coating is a 400 Å layer of vacuum-evaporated aluminum. Samples, up to approximately 2 by 1 by 1 cm, are examined on a specimen stage capable of three-dimensional movement, as well as rotation and tilting, within the vacuum chamber of the SEM.

TABLE 2

SEM EXAMINATION OF PHYSICAL EVIDENCE

Object	Characteristic	Maximum Useful Magnification	
		Optical Microscopy	SEM
Copper Clad Lead Bullet	Rifling Grooves	500×	1000×
Cartridge Case	Firing Pin Impression	50×	300×
Cartridge Case	Extractor Impression	100×	4000×
Iron Wire	Wire Cutter Impression	300×	3000×
Fingernails	Longitudinal Striations	200×	100×

FORENSIC APPLICATIONS

Because of the unique capabilities of the SEM, a number of objects frequently encountered as physical evidence were examined in an attempt to define advantages of this new microscopic device. Results of the SEM analyses are summarized in table 2 and are described in some detail in the text and micrographs which follow.

Two .45 ACP copper clad lead projectiles were recovered after firing and examined for striations produced by the barrel rifling. Optical micrographs of the bullets are shown in figure 2. The micrographs picture a bullet mounted on a SEM specimen holder to indicate the approximate size of sample suitable for convenient viewing. Figure 3 illustrates the detail possible for the matching of the rifling grooves of the two bullets by means of SEM analysis. The higher magnification used for matching of the rifling grooves in the SEM micrographs shown in figure 3 is approximately 300×.

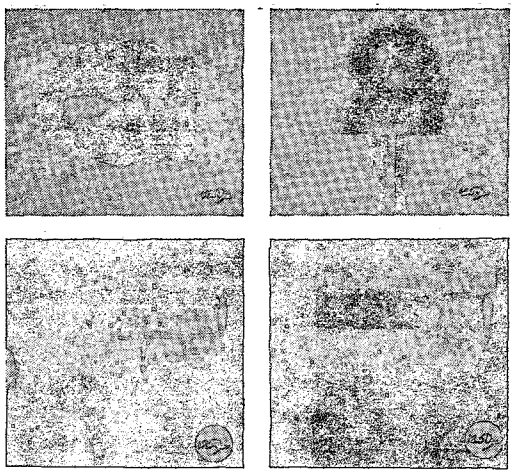

FIGURE 2
Optical micrographs of .45 ACP bullet. Top: Bullets on SEM specimen mounting. Bottom: Rifling grooves on the two bullets. Scale given as diameter of white circle in microns (μ).

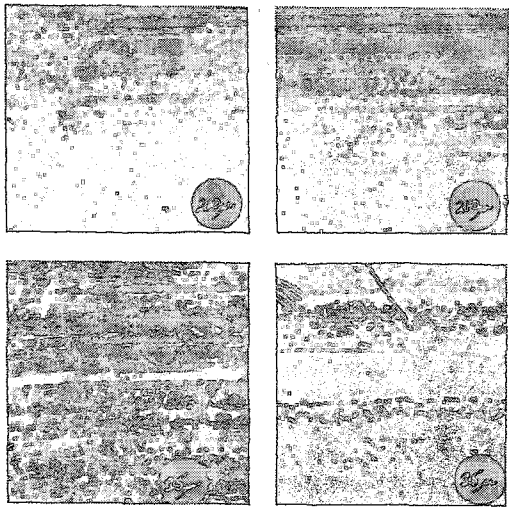

FIGURE 3
SEM micrographs of .45 ACP bullets. Top: Matched rifling grooves of two bullets pictured in Figure 2. Bottom: Matched rifling grooves of same bullets.

Note that the greater magnification does not help this comparison and, if anything, it is more confusing. It will be demonstrated in succeeding examples that more detailed markings can be found on objects composed of relatively hard metals such as iron and brass than on objects made of soft metals such as copper and lead.

There are a number of characteristic markings which can be found on cartridge cases; these include firing pin impressions and imprints made by

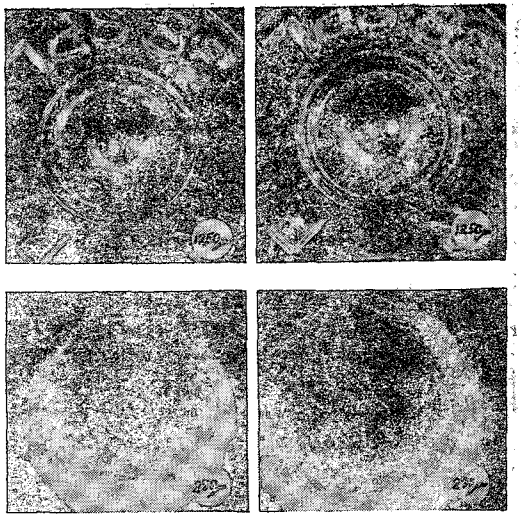

FIGURE 4
Micrographs of firing pin impression in .38 SPL cartridge cases. Top: Optical micrographs illustrating depth of focus limitations. Bottom: SEM micrographs showing superior depth of focus.

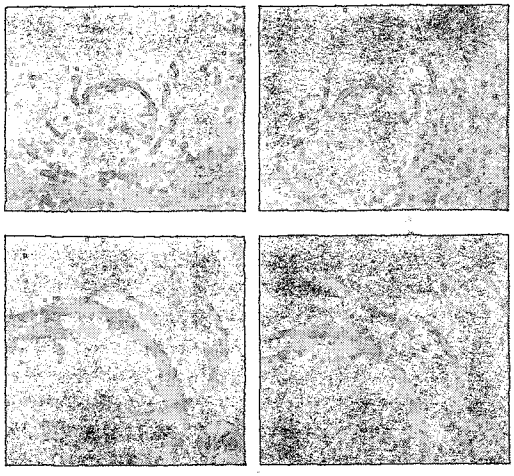

FIGURE 5
SEM micrographs of firing pin impression. Top: Detail at center of pin impression in two cases. Bottom: Increased detail of pin impression in two cases.

the breechblock, extractor, and ejector of the weapon. Since detail in this type of marking tends to be found at the bottom of impressions, the great depth of focus of the SEM provides a distinct advantage over other forms of microscopic examination. Figures 4 and 5 show optical and SEM micrographs of firing pin impressions in two .38 SPL cartridge cases. Similar distinguishing topography on the bottom surface of the two impres-

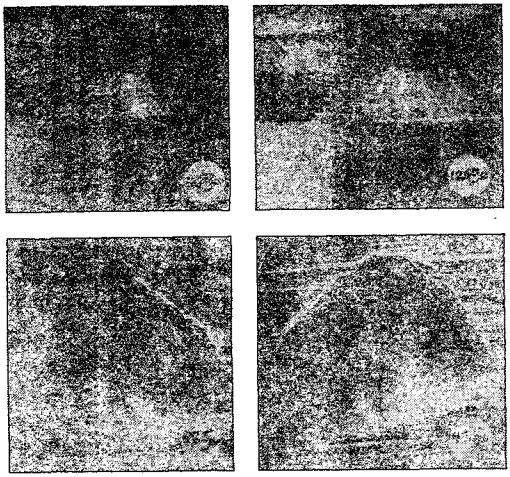

FIGURE 6
Micrographs of extractor markings on .45 ACP cartridge cases. Top: Optical micrographs of extractor markings. Bottom: SEM micrographs of portion of extractor markings above.

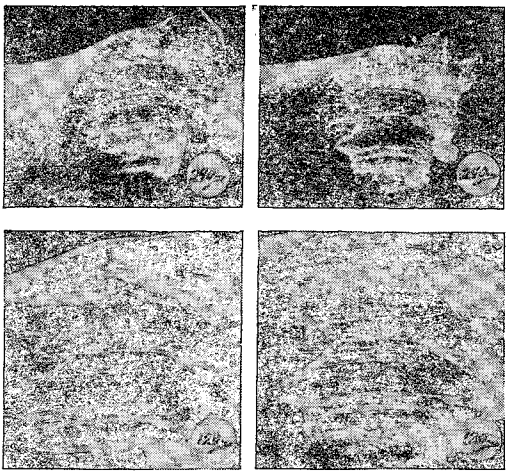

FIGURE 9
SEM micrographs of cut ends of 18-gauge iron wire. Top: Low magnification micrograph picturing excellent depth of focus of the two cut end surfaces. Bottom: Micrograph of the two cut surfaces illustrating the overall matching character of both specimens.

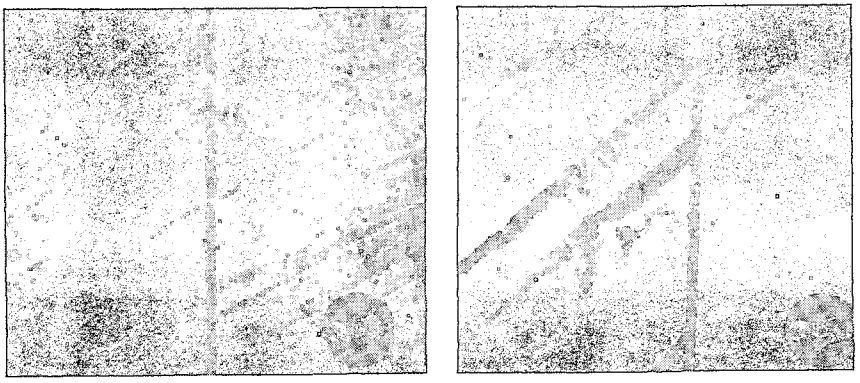

FIGURE 7
SEM micrographs of match extractor markings on two cartridge cases.

sions is clearly demonstrated in the SEM micrographs at 300× magnification. Extractor identations on two .45 ACP cartridge cases are pictured in figures 6 and 7. Groove matching at high magnification is portrayed in the SEM micrographs. Similar detail could be found but with more difficulty in the case of breechblock and ejector markings. Detail was not easy to resolve in the latter two instances because of tooling grooves on the cartridge cases.

The surface of the cut ends of wire carry impressions of the shape and contour of the cutting edge of pliers or wire cutters. A comparison of the information obtainable from optical micrographs of two 18-gauge iron wire ends cut with the same wire cutters as contrasted to SEM micrographs is recorded in figures 8, 9, and 10. The optical micrographs pictured in figure 8 indicate that the light microscope has definite limitations for examining such irregular surfaces. The optical micrographs are of poor quality compared to the SEM micrographs in figures 9 and 10 which show excellent resolution and detail from magnifications of 100 to 3000×.

For a number of years one of us (MacDonell) has collected fingernails to determine whether the pattern of longitudinal growth striations remains unchanged over a long period of time. A similar

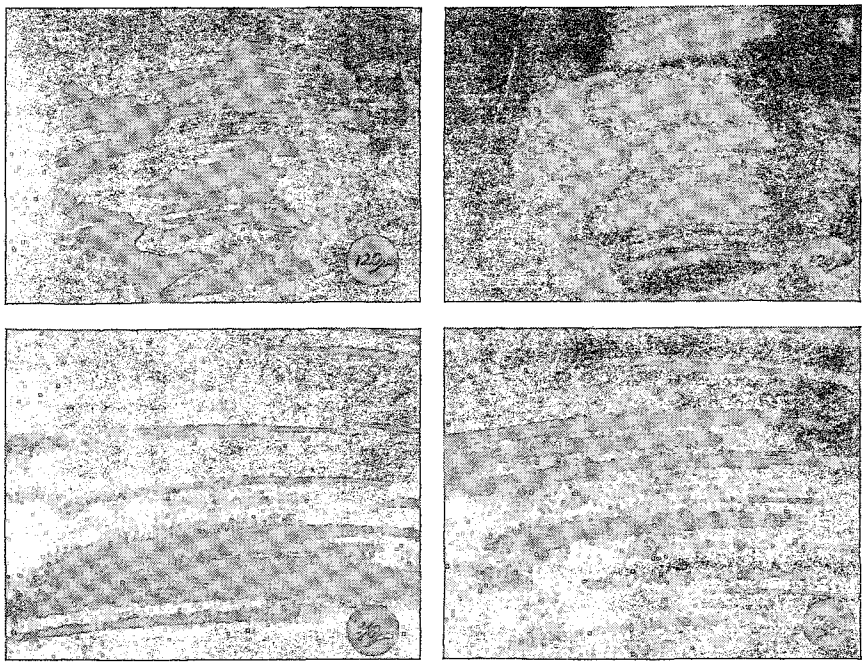

FIGURE 8
Optical micrographs of cut ends of 18-gauge iron wire. Top: Micrographs of two wire cuttings. Bottom: Micrographs of the cut surfaces showing maximum useful resolution of optical microscope examination.

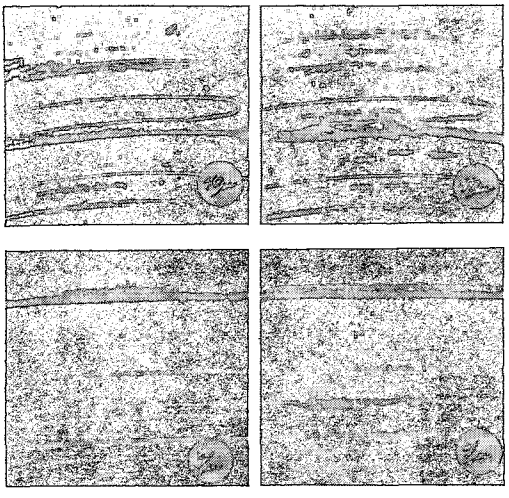

FIGURE 10
SEM micrographs of detail in surface topography of iron wire cuttings. Top: Detail of loop in center of micrographs pictured at bottom of Figure 9. Bottom: High magnification matching of wire cutting grooves shown at center above. The total cross section illustrated (top to bottom) is less than $\frac{1}{100}$th of the diameter of a human hair.

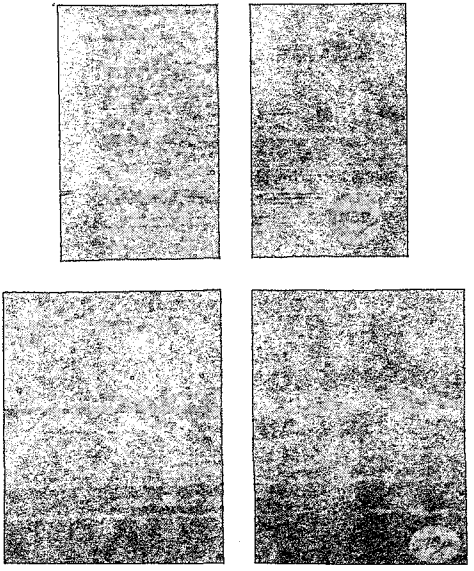

FIGURE 11
Micrographs of fingernail sections collected one year apart. Top: Optical micrograph of Al coated specimens using reflected light. Bottom: SEM micrographs of two fingernail sections showing matching striations.

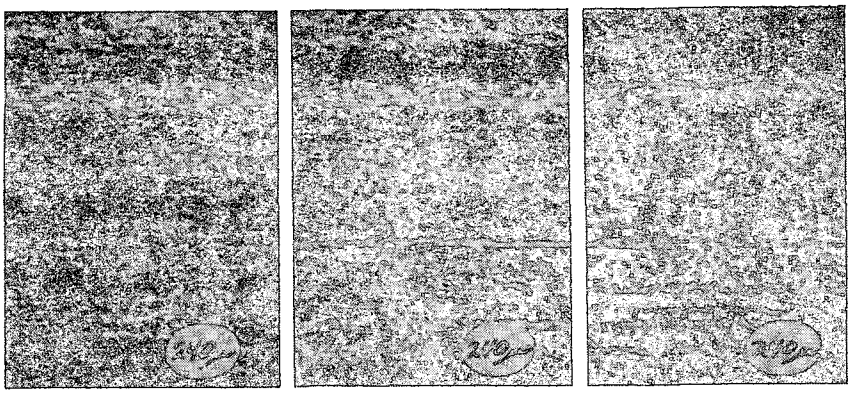

FIGURE 12
Composite SEM micrograph of fingernail sections collected over time interval of five years.

investigation was reported in 1965 by Thomas and Baert (7) who used a light microscope to evaluate and match striations. While some detail is present on the top surface of fingernails, the area is usually abraded and polished to such a degree that it is of little value for identification. The underside, however, contains much more detail as can be seen in figures 11 and 12. The aluminum conductive coating deposited on the fingernail specimens for SEM examination also improved the clarity of the reflected light optical micrographs. Both the optical and the SEM micrographs in Figure 11 present matched longitudinal striations of sections of two fingernails collected about one year apart. Figure 12 pictures a composite SEM micrograph of striations of three fingernail clippings collected at time intervals of about one and one-half years between each specimen. Note that the agreement of striations is more apparent when the viewer holds the illustration so they run in a vertical rather than a horizontal configuration. This is true for any striation comparison.

CONCLUSION

The SEM can be utilized to advantage for the direct examination of surface topography on physical evidence of forensic interest. The great depth of focus and high resolutions of the emissive mode of the SEM can reveal important microstructural detail not readily obtained by other microscopic means. While not employed in this study, the luminescent and conductive modes of the SEM could also prove valuable in criminalistic investigations.

ACKNOWLEDGMENTS

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