James Hillier 1915-2006
Contributions to Electron Microscopy

Official portrait as MSA President in 1945.

Informal picture after retirement from RCA.

Background

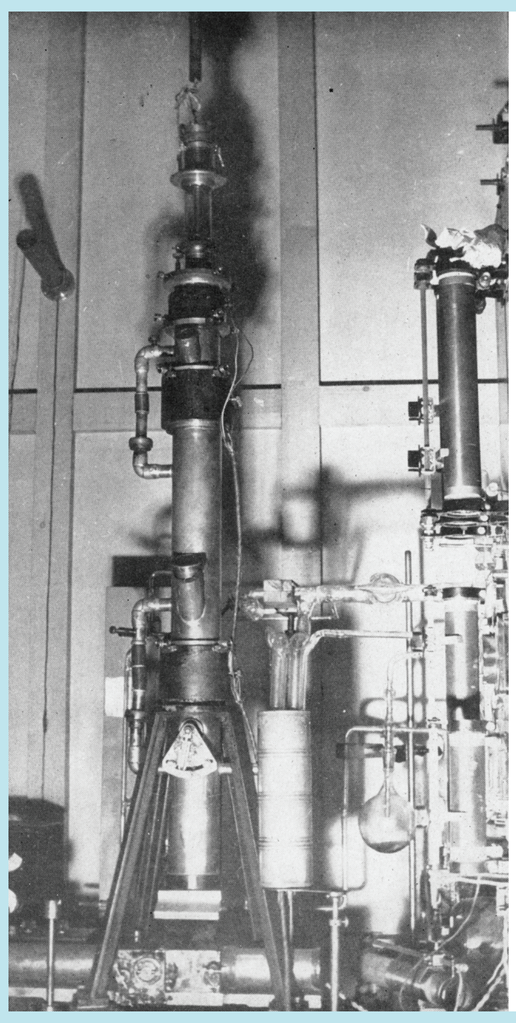
James Hillier's involvement with electron microscopy lasted only 16 years, from 1937 to 1953, but these were very productive years and he made many contributions to the new technology.

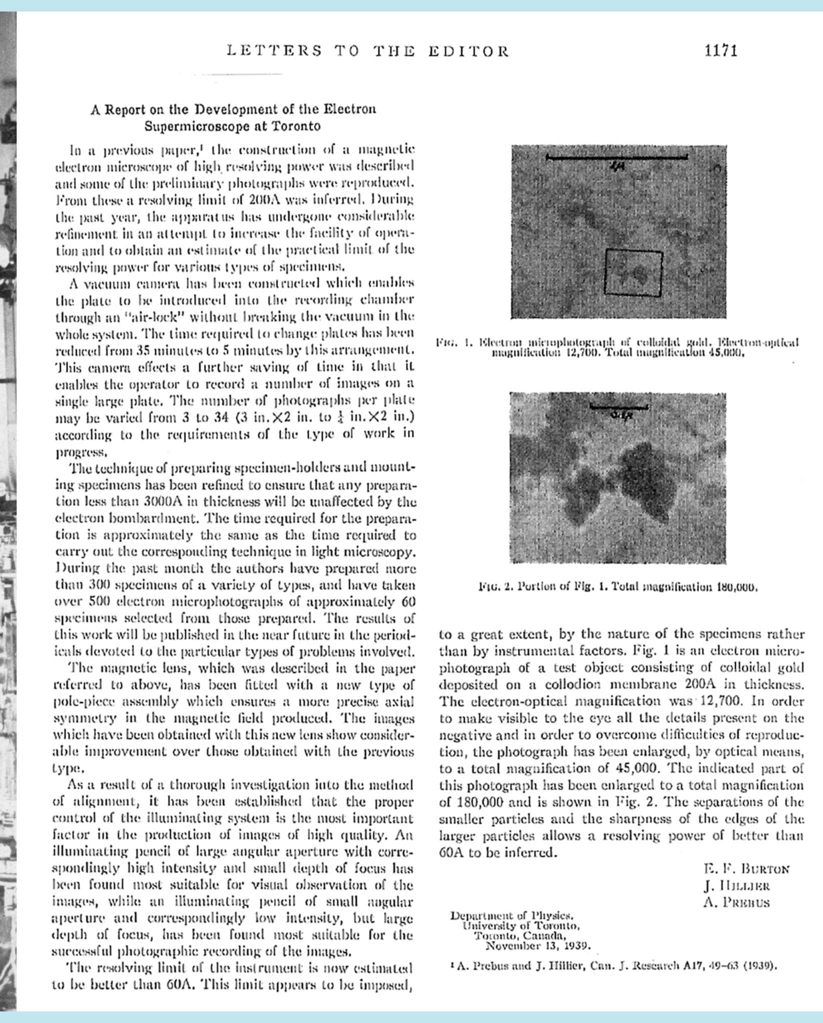
James Hillier was born in Brantford, Ontario, August 22, 1915. His family had come from artists, writers and musicians, although his father was a mechanical engineer. He graduated from the University of Toronto with a B.A. in 1937, M.A. in 1938, and Ph.D. in 1941. He was married in 1936 to Florence Marjory of Brantford Ontario, and has two sons: James Robert and William Wynship. His papers are kept at the James Hillier Foundation in Brantford

Although holding forty patents for devices and processes for improvements in the fields of electron microscopy, electron diffraction, electron microanalysis, ultra-thin sectioning, and viral and bacteriological techniques, Hillier said: "I never invented anything; I just solved problems".

Patents

Electron microscope (U.S. Patent No. 2,354,263; 1944);
Electron microanalyzer (No. 2,372,422; 1945),
Electron probe analysis employing x-ray spectography (No. 2, 418, 029; 1947),
Correction of distortion in electron lens systems (with R. F. Baker; No. 2,418,349; 1947),
Method of operating electron guns (No. 2,444,700; 1948),
Correction device for electron lenses (No. 2, 469,165; 1949),
Method and apparatus for electronically determining particle size distribution (No. 2, 494. 441; 1950).





LETTERS TO THE EDITOR 1171

A Report on the Development of the Electron Supermicroscope at Toronto

In a previous paper,[1] the construction of a magnetic electron microscope of high resolving power was described and some of the preliminary photographs were reproduced. From these a resolving limit of 200A was inferred. During the past year, the apparatus has undergone considerable refinement in an attempt to increase the facility of operation and to obtain an estimate of the practical limit of the resolving power for various types of specimens.

A vacuum camera has been constructed which enables the plate to be introduced into the recording chamber through an "air-lock" without breaking the vacuum in the whole system. The time required to change plates has been reduced from 35 minutes to 5 minutes by this arrangement. This camera effects a further saving of time in that it enables the operator to record a number of images on a single large plate. The number of photographs per plate may be varied from 3 to 34 (3 in.×2 in. to ¼ in.×2 in.) according to the requirements of the type of work in progress.

The technique of preparing specimen-holders and mounting specimens has been refined to ensure that any preparation less than 3000A in thickness will be unaffected by the electron bombardment. The time required for the preparation is approximately the same as the time required to carry out the corresponding technique in light microscopy. During the past month the authors have prepared more than 300 specimens of a variety of types, and have taken over 500 electron microphotographs of approximately 60 specimens selected from those prepared. The results of this work will be published in the near future in the periodicals devoted to the particular types of problems involved.

The magnetic lens, which was described in the paper referred to above, has been fitted with a new type of pole-piece assembly which ensures a more precise axial symmetry in the magnetic field produced. The images which have been obtained with this new lens show considerable improvement over those obtained with the previous type.

As a result of a thorough investigation into the method of alignment, it has been established that the proper control of the illuminating system is the most important factor in the production of images of high quality. An illuminating pencil of large angular aperture with correspondingly high intensity and small depth of focus has been found most suitable for visual observation of the images, while an illuminating pencil of small angular aperture and correspondingly low intensity, but large depth of focus, has been found most suitable for the successful photographic recording of the images.

The resolving limit of the instrument is now estimated to be better than 60A. This limit appears to be imposed, to a great extent, by the nature of the specimens rather than by instrumental factors. Fig. 1 is an electron microphotograph of a test object consisting of colloidal gold deposited on a collodion membrane 200A in thickness. The electron-optical magnification was 12,700. In order to make visible to the eye all the details present on the negative and in order to overcome difficulties of reproduction, the photograph has been enlarged, by optical means, to a total magnification of 45,000. The indicated part of this photograph has been enlarged to a total magnification of 180,000 and is shown in Fig. 2. The separations of the smaller particles and the sharpness of the edges of the larger particles allows a resolving power of better than 60A to be inferred.

Fig. 1. Electron microphotograph of colloidal gold. Electron-optical magnification 12,700. Total magnification 45,000.

Fig. 2. Portion of Fig. 1. Total magnification 180,000.

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November 13, 1939.

[1] A. Prebus and J. Hillier, Can. J. Research A17, 49–63 (1939).

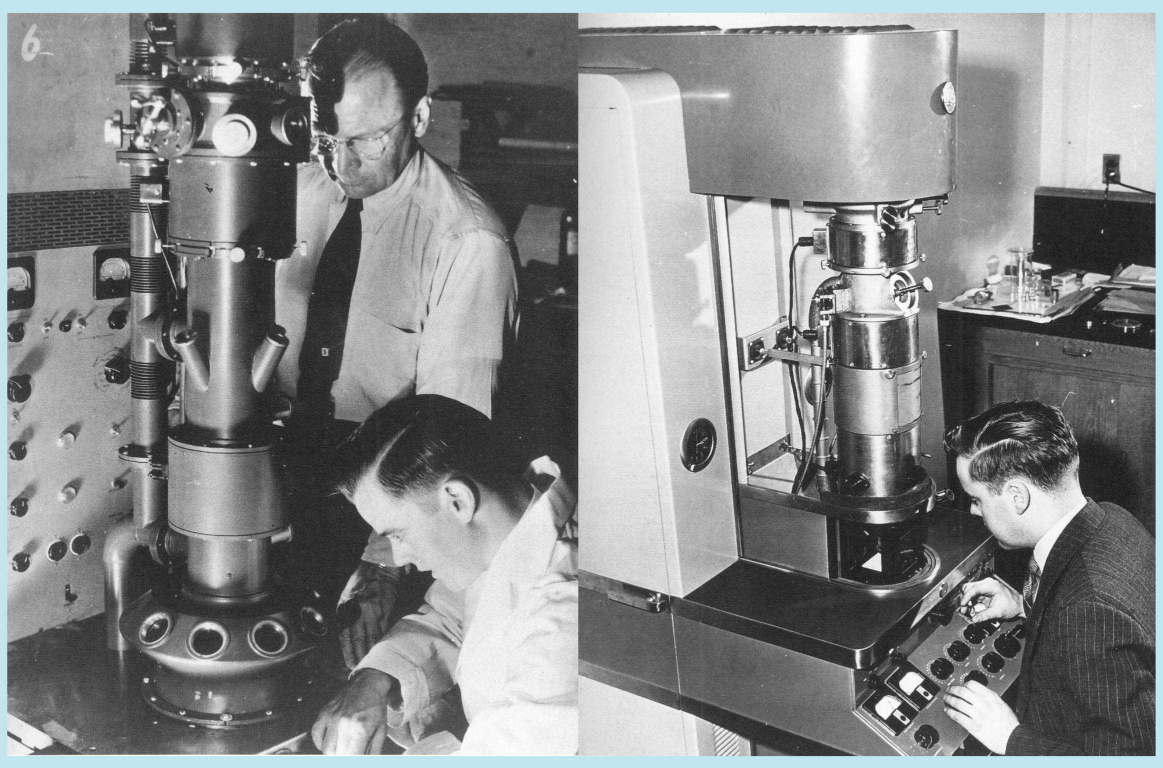
The improved Toronto microscope in 1939 (Burton et al., 1939). The 1938 EM had a resolution of 20 nm, and now 6 nm was reached, keeping pace with the first commercial Siemens Üm 100, which offered 10 nm resolution.

The Toronto microscope

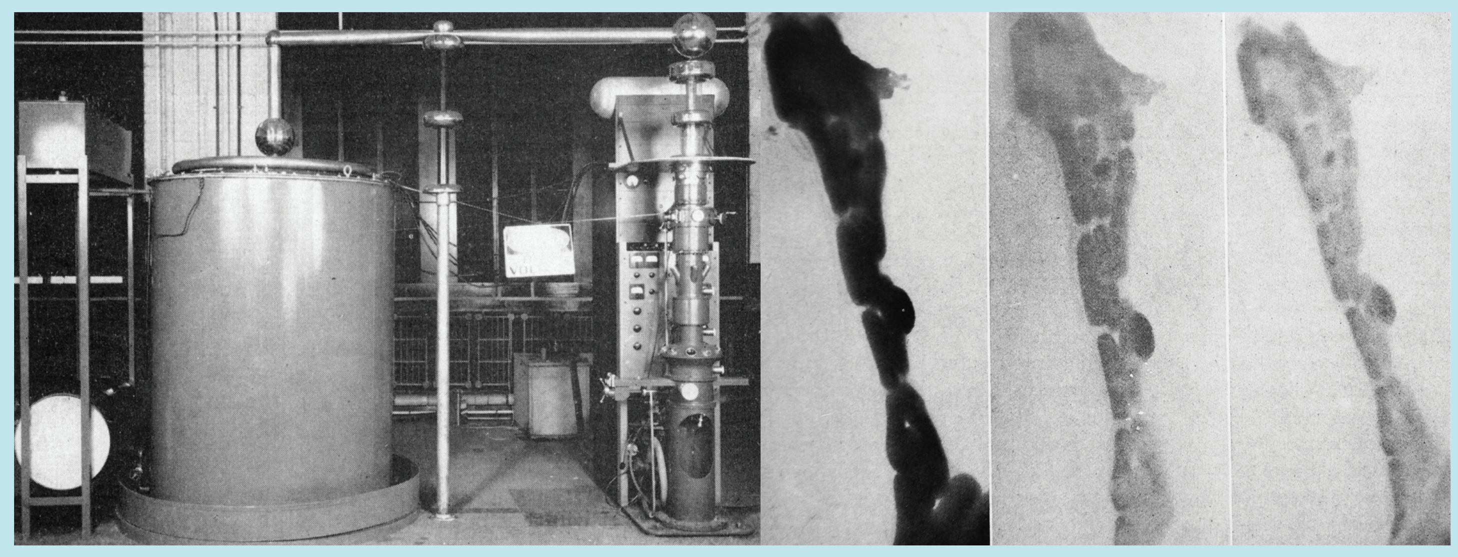
The story of the 1938 Toronto microscope, the first high-resolution EM in the Americas, has been told many times. It is remarkable that Hillier and Albert Prebus, as graduate students at the University of Toronto under Prof. E.F. Burton, designed the microscope over the Christmas break of 1937, and built the microscope entirely by themselves, in four months, getting the first images in April, 1938. The resolution of the first microscope was steadily improved, and by 1939 it reached 6 nm, on a par with the performance of the Ruska's, EM being developed at Siemens in Germany.

Hillier had to learn fine machining, since the machinist at the university had been trained on railroad locomotives, and six inches was already very small for him. Later, as vice-president of research for RCA, Hillier observed that his best engineers all had spent time working in a machine shop. Hillier's early hobby as an amateur radio operator helped him in designing the high-voltage supply for the EM (the lenses were operated by batteries).

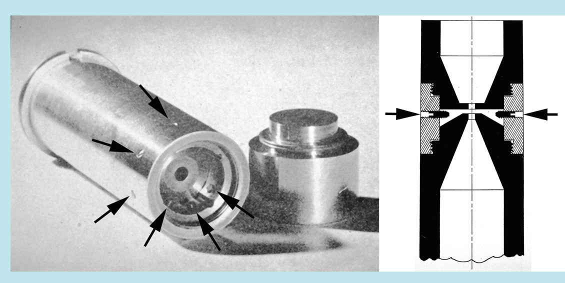
The success of the prototype led to a flood of visitors with specimens, and Hillier first considered starting a company to manufacture EMs, but soon realized that the financing would not be possible. Nevertheless, he wanted to make the EM available, so he went to GE and RCA, realizing that companies with the resources for such a major project simply didn't exist in Canada. GE showed only mild interest, but at RCA, he was asked "how soon can you build one?".



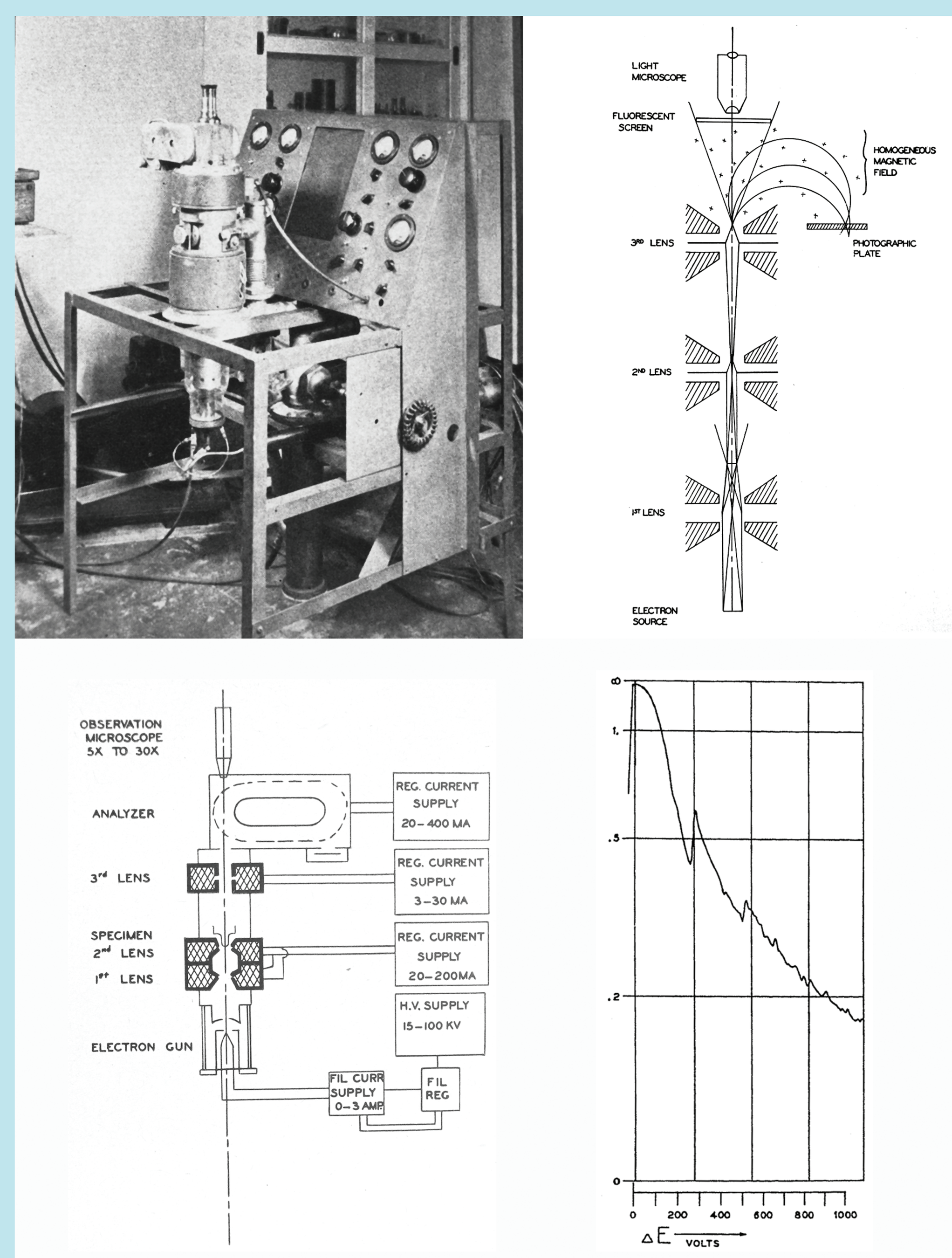
RCA's first commercial EM the EMB, in 1940, (left) operated by Hillier with Alexander Zworykin, RCA's research chief and instigator of the EM project, looking on. This was followed in 1943 by the RCA "universal" EM, the EMU (right), which was capable of both imaging and diffraction.



The RCA 300 kV EM (Zworykin et al., 1941). Because of the difficulty in finding specimens of interest that were thin enough, and in cutting good thin sections, higher acceleratin voltage seemed to be the answer. The specimen is the bactrerium *B. megatherium*, recorded (left to right) at 50, 200, and 250 kV.



The first objective lens stigmator (Hillier and Ramberg, 1947). Soft iron screws (arrows) were inserted into the polepiece spacer. This brought the resolution down to 1 nm, a major advance.



The first energy-loss spectrometer operated as an electron microscope (Hillier and Baker, 1944). The minimum probe size was 20 nm. There was only a single stage of image magnification, so the fluorescent screen was viewed with a light microscope. The spectrum was recorded on photographic film. The spectrum shows the carbon and oxygen K-edges from a collodian film.

EM work at RCA

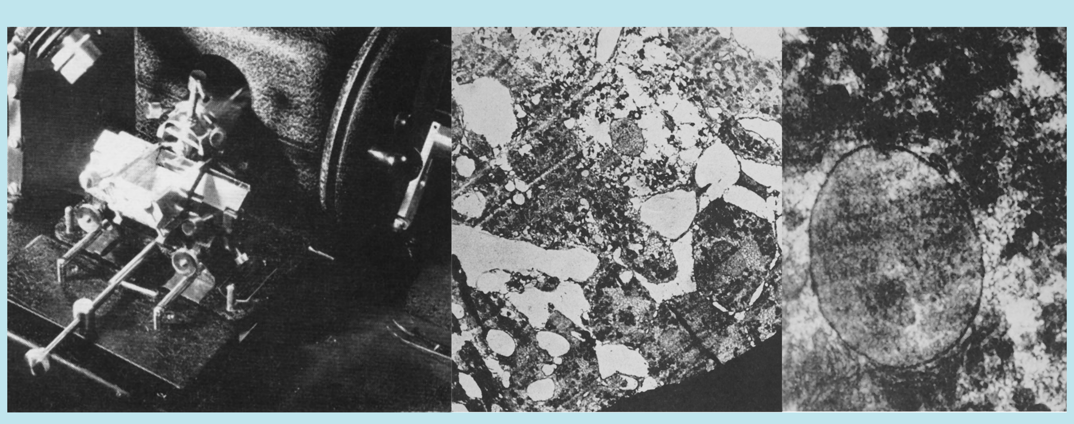
The first commercial EM in America came from the convictions of Vladimir Zworykin at RCA (the "father of television" in America). First, in 1939, Zworykin got money to start the EM program by telling RCA administration that Russia was interested in purchasing EMs. Ladislav Marton, a Belgian EM pioneer (credited with the first biological electron micrograph) was hired, and the RCA Model A was constructed. Zworykin determined that this EM would not be a viable commercial product.

Once Hillier was hired (February 1940), the Model B was ready by July 4. Why the hurry? Zworykin had spent all his research money on the Model A, but he knew that the accounting would not be made for another four months, and in that time, he gambled that Hillier would already have built the new model. The prototype was sold to American Cyanimid for $10,000, paying for the development cost, and convincing RCA to continue the EM program.

The prototype EMs had so many factors contributing to decreased resolution that progress was very slow at first, since any one improvement made only a small difference. A breakthrough came in 1947, when Hillier realizing that astigmatism was due to the asymmetric magnetic field caused by inhomogenencies in the soft iron objective polepiece, came up with the idea of the ""stigmator", which at first was simply soft iron screws tapped into the polepiece. This gave an immediate 4 times improvement in resolution (to 1 nm), and has been incorporated in all EMs ever since.

Hillier contributed heavily to both EM theory and technology. Please see the reference list, below, which reflects his wide range of theoretical and applied work. Early on, he built a 300 kV TEM. He analyzed the effects of chromatic aberration and established principles for an optimal illumination system. He built the first SEM with a secondary-electron detector using a post accelerator and a photomultiplier tube. He built the first energy-loss spectroscopy electron microscope.

But his ultimate interest was in putting the EM to work to solve scientific questions, particularly in medicine (see selected references). Working with Stuart Mudd of the University of Pennsylvania, and other collaborators, the RCA EM lab became an applications center, where people could learn how to prepare specimens and how to interpret micrographs. This was consciously done in such a way as to relate the EM images with the light microscope images that people were familiar with. Hillier understood that the new technology would not be accepted if the results could not be understood in terms of existing knowledge. His work on specimen preparation was critical in this regard, and he made important contributions to ultramicrotome development.



An improved ultramicrotome (Hillier and Gettner, 1950a,b). Artifacts associated with earlier ultramicrotomy work by Pease and Baker (J. App. Phys. 20, 480, 1949) were analyzed, and further modifications were made to a standard Spencer microtome. Cutting sections directly onto a water surface proved provide a method by which good sections could be obtained without the need to subsequently remove the embedding material. Good quality 200-nm-thick sections could routinely be obtained. Sections shown are of liver tissue.

The first surface-scanning microscope (Zworykin et al, 1942), and the first with secondary electron detection by a phosphor and photomultiplier. The original intent was to run at TV-rate, and a cold field-emission source was required for sufficient brightness. The specimen and the source were sealed in an evacuated tube, which was placed into the lens system. Some images were obtained (FEG SEM in 1942!), however, the tips were not reliable, so a conventional thermionic was used, requiring a slower scan rate. The resolution was about 50 nm.

Research direction at RCA

In 1953 Hillier left EM. He realized that he would never be able to be a creditable medical researcher, lacking the appropriate academic credentials, and looked for other challenges. After stint as director of research for the ill-fated Central Research Laboratory of Westinghouse Air Brake, where he nevertheless quickly learned how to do the job properly, he came back to RCA. In 1955-1956 he was chief engineer of RCA Industrial Electronics Products, Camden, N. J. He became General Manager of RCA Laboratories in 1957, and in 1958 became Vice President, RCA Laboratories, responsible for directing the research programs and the administration of RCA's central research facility. In 1968 he became Vice President, Research and Engineering and in early 1969, Executive Vice President, Research and Engineering. In these positions he had corporate responsibility for all of RCA's research, development and engineering programs. He was highly respected in the research community for his ability to pick creative engineers and manage them in such a way as to maximize their potential, while being able to accurately asses the commercial potential of a new technology. He retired in 1977, after championing the RCA videodisc, a consumer product which he judged had great potential. Unfortunately, after he retired, the videodisc was eclipsed by the VCR. Perhaps he was ahead of his time, the VCR has now been eclipsed by the DVD.

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