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[IBM Corp., Thomas J. Watson Research Center, Yorktown Heights, NY]

The potential of using electron beams as lithography tools for micrometer and submicrometer solid-state device fabrication was recognized by many workers by the mid-1960s. Work on electron sensitive resists and processes, however, had not progressed to the state required to realize this potential. This paper provided information on the use of poly- (methyl methacrylate) (PMMA) as a very high resolution electron resist and also introduced the 'lift-off' process of metallization as a method for fabricating very fine line conductors, necessary for any small device fabrication. [The SCI® indicates that this paper has been cited in over 115 publications since 1969.]

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"I joined IBM in 1961, almost one year after the official opening of the new Thomas J. Watson Research Center at Yorktown Heights, New York. At that time a small group of people had been assembled by A.V. Brown to work on electron beam uses primarily for recording information on photographic films. By 1964 it became clear to us at IBM, as well as to people in other laboratories such as Westinghouse Research and Texas Instruments, Inc., that electron beams would be very useful in the lithographic processes that are used to define all transistors and integrated circuits on silicon or other semiconductor materials. From the point of view of packing density and device operation speed, there was clear interest, even at that time, in processes that would allow the fabrication of devices with minimum dimensions of less than one micrometer. Electron beams could certainly be focused to much smaller dimensions, as was demonstrated by the scanning electron microscope (SEM) developed as a practical instrument primarily at Cambridge University in England.

"By 1964, we had also built a 'home' version of a scanning electron beam system, under the guidance of Richard Thornley from Cambridge University, and managed to attach to it an optical flying spot scanner system with a high resolution CRT that made it possible to write patterns on silicon wafers with the electron beam without the use of computers. At the same time I asked for the cooperation of two people in the physical sciences department in our lab, R. Srinivasan and Ivan Haller, and the search for electron sensitive materials was started. After testing a very large number of polymers, we came to the conclusion that poly- (methyl methacrylate) (PMMA) appeared to be the most promising, especially from the point of view of resolution, which was key to any electron beam fabrication process.¹

"After this conclusion I embarked on a detailed evaluation of PMMA as an electron resist and, with the cooperation of Thornley and V.A. Dhaka of the IBM East Fishkill Laboratory, started thinking of the processing steps and design required to fabricate one micrometer size bipolar transistors.² Most of the structures that I used in the optical flying spot scanner to demonstrate the resolution capabilities of various resists were obtained by cutting finely ruled graph paper with a razor blade in order to generate the desired structure very quickly. In fact, most of the patterns shown in the article, including the one and the one-half micrometer transistor structures, were made this way. My work on the detailed evaluation of PMMA, which led to the publication of this paper, made two important contributions to the technology and these, I believe, constitute the reason for the frequent citation of the paper. First, it indicated that PMMA is superior to any other medium for high resolution electron beam lithography, a fact that remains true even today, almost 15 years later. Second, it introduced the 'lift-off' metallization technique³ to semiconductor fabrication, which made it possible to produce metal connectors of micrometer and submicrometer size, not possible then using any other technique. This process was the key to the fabrication of micrometer transistors and it established 'lift-off' as a new terminology in connection with semiconductor fabrication."

1. Haller I, Hatzakis M & Srinivasan R. High-resolution positive resists for electron beam exposure. *IBM J. Res. Develop.* 12:251-6, 1968.
2. Thornley R F M, Hatzakis M & Dhaka V A. Electron-optical masking of semiconductor structures. *IEEE Trans. Electron Devices* ED-17:961-4, 1970.
3. Hatzakis M. Semiconductor metalizing process. *IBM Tech. Disclosure Bull.* 10:494-5, 1967.