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Is Low Accelerating Voltage Always the Best for Semiconductor Inspection and Metrology?

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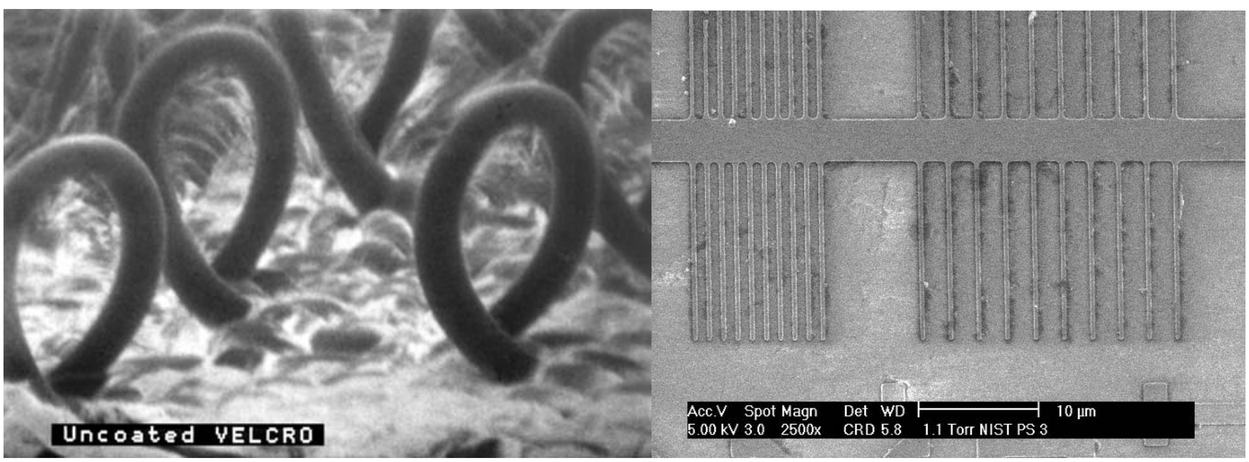
Low accelerating voltage operation is an excellent mode of scanning electron microscopy and it is extensively used for measurements in semiconductor production. The beam penetration is small, and if properly applied, the specimen charging is kept at acceptable levels. But, is this always enough? Today, the scanning electron microscope (SEM) is being used in photomask metrology and imaging where charging is excessive. Charging is difficult to quantify and control as it varies greatly with instruments, operating conditions and sample. Therefore, it is also very difficult to model accurately. For accurate metrology charging must be overcome because the dynamic charging of the sample deflects the electron beam from its intended position and the intensity of the induced signal may vary uncontrollably. Deflection of the electron beam of even a few nanometers potentially results in a measurement error that is significant to modern semiconductor production.

Low and ultra low accelerating voltage operation in the scanning electron microscope has always been possible but not always effective or practically useful. Figure 1a shows a 100 eV image of uncoated Velcro® [3] taken in 1987 with an SEM equipped with a lanthanum hexaboride electron source. Early work at Cambridge University and RCA Laboratories demonstrated the value of low accelerating voltage operation and for many years following, low accelerating voltage operation was done on a limited group of samples. High accelerating voltage SEM operation essentially became the common mode of operation because of the ease of obtaining high resolution and good signal-to-noise ratio, even if it came with the need to coat non-conductive samples with a thin layer of conductive materials. Most SEMs were designed to achieve high performance in this mode of operation; low accelerating voltage operation was limited because the electron guns with tungsten filaments and lanthanum hexaboride rods were not able to achieve good enough resolution and signal-to-noise ratio. Early field emission instruments were far from their ultimate capabilities.

In the mid-80s visionaries saw the need and possibility of the application of SEMs in the inspection and metrology of semiconductor production samples. Device and integrated circuit feature sizes were shrinking below the optical microscope capabilities achievable at that time. Low accelerating voltage operation was chosen for its potential of non-destructive imaging and due to the fact that conductive coating was unnecessary to minimize sample charging. Low accelerating voltage operation also provided small beam penetration into the sample and a more precise “look” at the surface structure. Imaging and information content was greatly different between high and low accelerating voltage operation and a great deal of new knowledge about the samples resulted. The higher brightness lanthanum hexaboride electron guns were being pushed to their limits, digital frame buffering was introduced and eventually field emission instrumentation became superior and proved their value of increased electron source brightness and higher resolution. All this took a lot of investment in research and development. Fortunately, the semiconductor industry was willing to pay for the development of special SEMs capable of meeting the needs of semiconductor production; in the meantime this development benefited all other SEMs. Hence, the low accelerating voltage “revolution” began. A trained operator could take SEM images of almost any sample without the need of conductive coating that otherwise often obscures fine surface details.

An alternative technique for semiconductor metrology and inspection that minimizes, if not eliminates the sample charging is environmental or high pressure scanning electron microscopy. It offers the advantage and possible application of higher landing energies or accelerating voltages, different contrast mechanisms and charge neutralization. Higher landing energies means that higher resolution imaging is possible than at the lower accelerating voltages. But of course, beam penetration is increased. This method employs a gaseous environment to help neutralize the charge build-up that occurs under irradiation with the electron beam. Although very desirable for the charge neutralization, for various technical reasons, this methodology has not been in use in semiconductor inspection or metrology until just recently. This is a relatively new application of this technology to this area and much still needs to be learned. But, as illustrated in Figure 1b, this technology shows great promise in the inspection, imaging and metrology of optical photomasks in a charge-free operational mode. In addition, this methodology affords a path that minimizes, if not eliminates, the need for charge modeling which is needed for higher accuracy measurements. The modeling of charging is exceptionally difficult since each sample, instrument and operating mode can respond to charging in different ways. Therefore, this methodology shows great potential if the optimal balance can be achieved in a reproducible manner. Further research is currently underway to understand the ways to optimize these operating conditions. This paper presents some new results in high pressure SEM metrology of photomasks.



a. b.

Figure 1. a) Ultra low accelerating voltage image of an uncoated Velcro® sample taken with 100 eV accelerating voltage in 1987 with an SEM equipped with a lanthanum hexaboride electron source. b) High pressure SEM image of a binary photomask demonstrating the lack of excessive charging even at relatively high accelerating voltage.

References

[1] Contribution of the National Institute of Standards and Technology, not subject to copyright.

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[3] Certain commercial equipment is identified in this report to adequately describe the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the equipment identified is necessarily the best available for the purpose.