

## Students and the SEM: The First Encounter

V.M.Dusevich, J.D.Eick

University of Missouri, Kansas City, MO

DusevichV@umkc.edu

The first demonstration of an SEM to students is a rewarding experience. Whether it is the beginning of a course in instrumentation or just an illustration of the abilities of an SEM for “prospective users”, whether students have engineering or biological backgrounds, both graduate and undergraduate students are thrilled to see a “real electron microscope”. We thus have an easy task of only having to choose the right specimens to fulfill their anticipation and to present the right amount of information that will be easily absorbed and remembered for a long time.

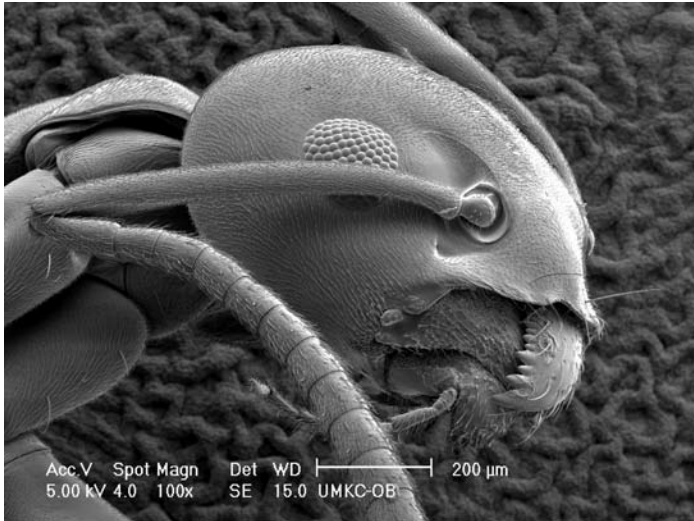


Figure 1. An ant.

Insects are the *prima donnas* of SEM imaging. We usually start our demonstrations with insects (Fig.1). Their multifaceted eyes, terrifying (at proper magnifications) mouths, exoskeletons, jointed limbs, and segmented bodies look so astonishingly alien under the microscope, so remarkably different from their familiar (to the naked eye) appearance, that insects unfailingly get the students thrilled and prepare them to absorb information. Most insects do not require any special preparation. A sun-dried insect collected on a deck or a driveway in dry weather makes a nice specimen.

While observing insects at various magnifications, we print an image on a video printer attached to the microscope and bring the students' attention to the fact that now we can see two similar images: one on an SEM monitor, which shows magnification, for example 1000x, and one on a small print, where the magnification is 373x. Surprisingly, most students are puzzled by the difference in magnifications, even though many of them have already used some type of microscope. Somehow the wrong idea that magnification is some instrumental constant gets imprinted in students' minds. Therefore, we have to

explain the interrelation between the size of the field of view on the specimen surface and the size of the final picture, and that by increasing the size of the picture we are increasing the magnification proportionally. We stress that as a result practically all shown magnifications for pictures in publications are wrong, and the courteous author will present pictures with a micron bar.

If our first specimens require some special specimen collection (usually outside a microscopy lab), our second set of specimens is available in any lab: it is two pieces of paper, writing paper and filter paper. We are now shifting the students' attention from creatures that are part of nature to man-made seemingly dull objects: plain, white, and featureless. After all the excitement with insects, students have pretty low expectations when we are switching to paper specimens and they are consequently surprised to see the complicated microstructure of paper. A tangle of pulp fibers looks pretty good on a micrograph of filter paper (Fig.2), and its morphology looks very different from the morphology of writing paper (Fig. 3 a). Switching accelerating voltage from 2 kV (see Fig. 3a) to 15 kV (Fig. 3b) transforms the image dramatically. With this example we can explain the importance of choosing the right acquisition parameters, depending on the purposes of observation. On a micrograph of writing paper we can see not just fibers,

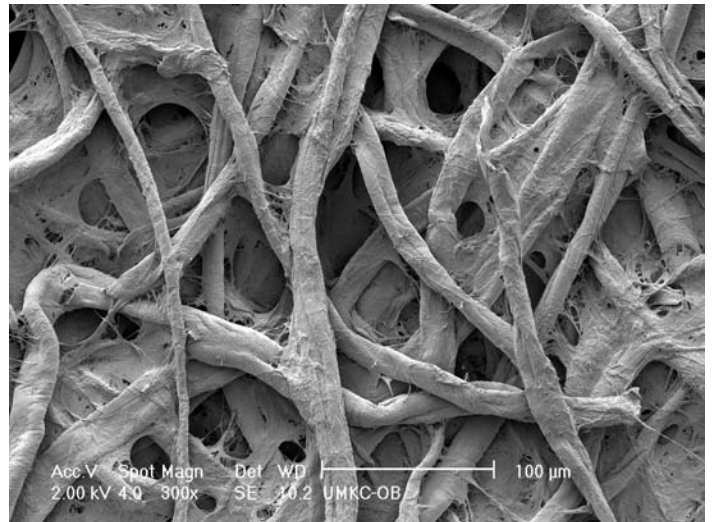
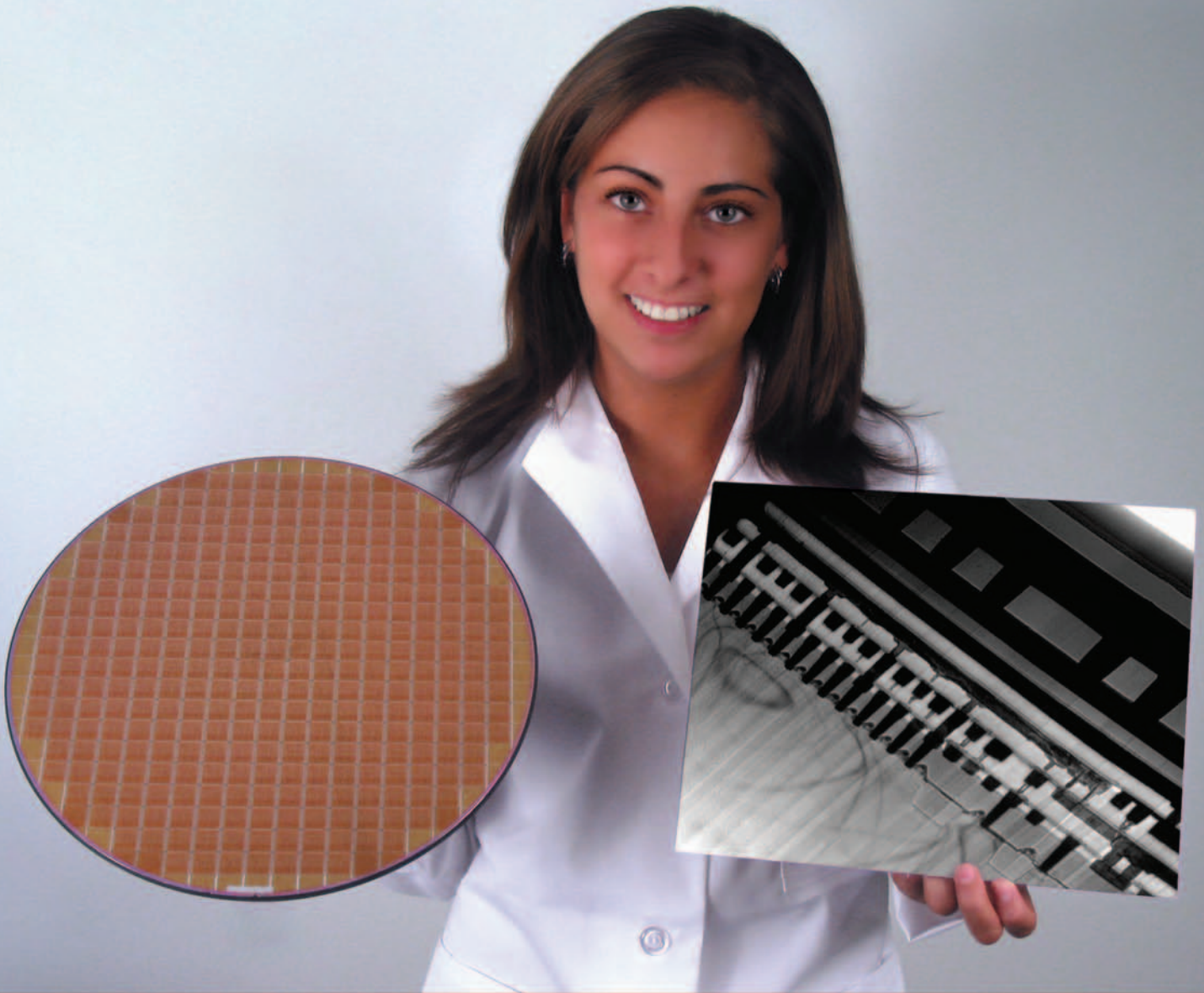


Figure 2. Filter paper (2 kV).

but also filler particles, which could consist of calcium carbonate (contains Ca), kaolin (Al and Si) or titanium dioxide (Ti). These filler particles are good objects for a demonstration of BSE imaging (Fig. 3 c) and EDS mapping (Fig. 4). At this stage we do not go into the details of electron beam interaction with a specimen (our time is very limited). We just state that there are three main signals generated in the interaction, and that each of these signals is acquired with a specialized detector; and that secondary electrons



Figure 3. Writing paper. Secondary electrons at 2 kV (left), at 15 kV (center), and backscattered electrons (right).



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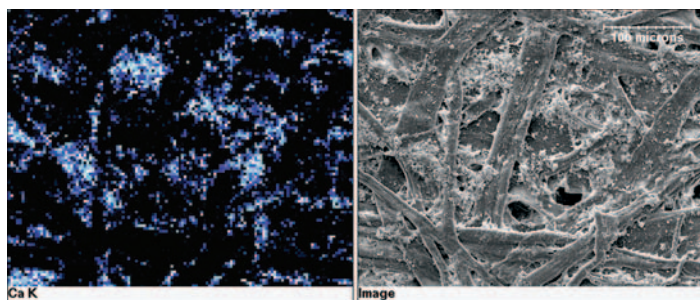


Figure 4. Distribution of Ca (in filler particles) in writing paper.

are best at reflecting topography, backscattered electrons are good for differentiating specimens' phases ( $z$ -contrast) and X-rays are indispensable in elemental analysis.

Our last set of specimens is of really dull (for SEM imaging) material, glass (round coverslips). So, we are gradually decreasing the visual attractiveness of our specimens to be able concentrate the students' attention on discussion.

The first glass specimen is a spatter coated coverslip. It is usually not a problem to find a place with a particle for focusing (Fig. 5). When the field of view is moved to a place without any particles, students are somewhat surprised to see that there is nothing to look at: just a monotonous monitor with the same brightness all over. We have to remind them that when we look at a piece of glass with a naked eye we also do not see any features of its surface, just light reflections. It is a good starting point for a brief discussion about some elements of image formation. We remind students that to obtain any information about the topography of a specimen, we need some kind of a probe and the means to register the results of its interaction with the surface of a specimen. We can use our finger as a probe and become familiar with the topography of an object with the help of our tactile sense. If we move fingers along a flat featureless surface our sensation will be the same in every spot, it will remain unchanged. The same is true for a light probe or for an electron probe — if there are no changes in specimen topography (flat surface), there will be no changes in surface interaction with a probe and the image will consist of a signal of the same intensity in every spot of a field of view. We can continue our “three probes”

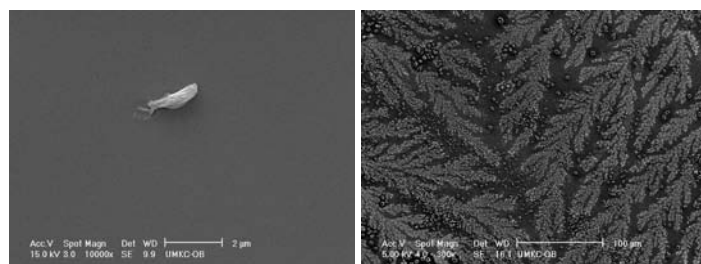


Figure 5 (left). Particle on a glass surface.

Figure 6 (right). Crystallized salts from tap water on glass surface.

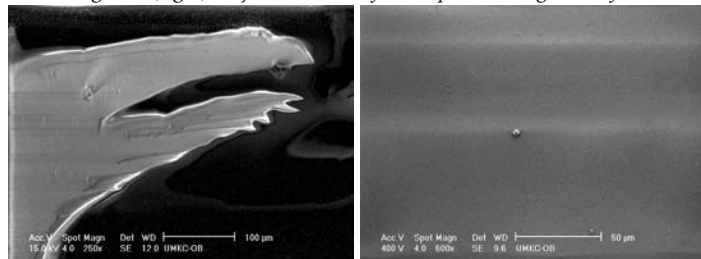


Figure 7 (left). Charging on an uncoated glass surface at 15 kV.

Figure 8 (right). Dust particle observed on an uncoated glass surface at 400 V; some charging could be observed.

analogy for a simple introduction of resolution. Again, if we use our fingers to get acquainted with a surface, we could not get any information about the topography of holes that are smaller than our fingers. So, in this case the spatial resolution is limited by the size of the fingers. When our eyes use light as a probe, especially when utilizing a light microscope, the spatial resolution is limited by light's “finger size”, *i.e.* its wavelengths. Finally, with electron microscopes we use electrons with shorter wavelengths and better resolution.

The next specimen is a coverslip “washed” with tap water, dried and spatter coated. There are a lot of salt crystals in spots where the last drops of water had dried out (Fig. 6). It leads to a discussion of artifacts in microscopy and the importance of proper specimen preparation.

The last specimen is a glass coverslip “as is”, not coated. Of course, it is good for the demonstration of charging. Charging could be very strong, as at 15 kV accelerating voltage, and generates images that are dynamically changing artifacts (Fig. 7). At 400 V, accelerating voltage charging is weak enough to allow us to observe the surface (really dust particles on surface) at low magnifications and fast scanning mode, but strong enough to demonstrate the increase of degree of charging at slower scanning modes (Fig. 8) and at increased magnifications.

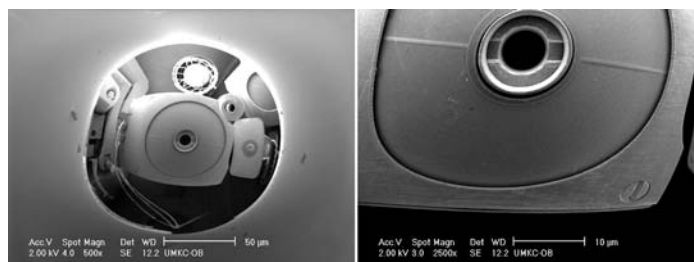


Figure 9. SEM specimen chamber observed due to reflection of an electron beam from highly charged glass surface; (a) “fish eye” view, (b) BSE detector at higher magnification. Magnification values and micron

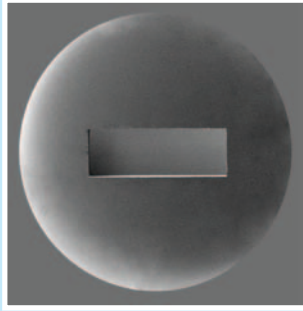
Finally, glass is good for the demonstration of “ultimate” charging. First we need to create a symmetrically charged region on glass. For this we switch the beam off, move to an uncharged (not previously observed) spot on the glass, set high voltage at 15–25 kV and scanning mode to a spot, turn the beam on and charge the glass for about 10 seconds. Then we can set the voltage to 2 kV and get an image of the specimen chamber (Fig. 9 a), a really nice “fish eye” view of the specimen chamber with an eye in the place of the specimen. The charge is rather stable and we can change magnification, move the image and focus on some details, such as detectors, wires, etc. (Fig. 9 b) The explanation of the observed effect is simple: the electron beam, while scanning the surroundings of a highly charged spot, gets reflected in the direction opposite to the direction of the spot. In this way the reflected beam is scanning the specimen chamber so that its virtual spot of origin coincides (with minor distortions) with the charged spot. What we see on the SEM monitor is a signal produced by the beam interacting with the surfaces of the specimen chamber. The students, seeing that with simple manipulations we converted our specimen to a device for the observation of specimen chamber, get excited again, almost as much as when seeing insects. And excitement, we believe, helps them remember lessons.

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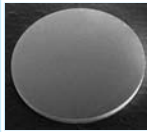
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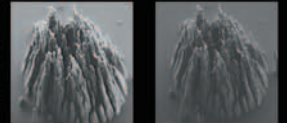
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