Is the TEM Obsolete?

D. B. Williams, Lehigh University

In 1968, as an undergraduate, I was first taught how to operate a Philips EM300 TEM that, at the time, was a state-of-the-art 100 keV TEM for materials studies. Last year, I spent time evaluating current state-of-the-art microscopes, *i.e.*, intermediate-voltage, field-emission gun TEMs, from all the major manufacturers. In watching the operators running these latest microscopes, I was struck by the similarity between many of their actions and the same steps that I had learned, so laboriously, 30 years previously.

After the specimen is loaded, there are five basic operations required to run a TEM, most of which require significant manual dexterity:

a) Move the specimen; this usually requires both hands.

b) Tilt the specimen; this usually requires at least one hand, and often one or more feet, if the second tilt axis is used and the specimen loses eucentricity. The other hand is used to compensate for the inevitable specimen movement.

c) Form a DP; use one hand to insert the SAD aperture, two hands to center the aperture, push a button with another hand to switch to diffraction mode and focus the DP, by hand, using another control.

d) Form a BF image; use one hand to insert the objective aperture, two hands to center the aperture, push a button with another hand to switch to image mode, use a hand to remove the SAD aperture and focus the image, by hand, using another control.

e) Tilt/traverse the beam; use two hands to balance the potentiometers for a CDF image and two hands to center the beam after any condenser-lens adjustment (e.g. change in spot size) or significant change in magnification.

In a small fraction of TEMs in the field, operation a), above is under full computer control and operation b) is under partial control. In all TEMs, the rest of the operational procedures c), d) and e) (which constitute the bulk of routine TEM operation) still require manual manipulation of electro-mechanical controls (knobs, buttons and potentiometers). These controls may be digitized, but the fundamental manual operations are essentially the same as when they were analog. I believe this was acceptable decades ago when command of analog controls was an essential characteristic of an experimental engineer/scientist. It should not be the case now that mastery of a mouse is a ubiquitous skill, particularly amongst students.

The operation of the TEM is so obtuse that, without careful instruction, the novice will simply thrash around for many weeks, or even months, without making much progress. This was true in the days of my early training and it remains true for today's students. Which other leading-edge scientific instrument is essentially unchanged in its operation (and therefore its design) over the last thirty years? I cannot think of any - not even the old light optical microscope, which has undergone a revolution in its design and operation with the development of near-field and confocal optics as well as digital CCD recording of images.

My view of the stasis in TEM development is not new: Alwyn Eades asked the following question at the Higgs Meeting in Giens, France, in 1989:

"Will it always be true that *manual dexterity* is more important than *intellectual dexterity* in the practicing (transmission) electron microscopist?"

I think it betrays a serious lack of progress in our field to note that, a decade after that question was first posed, it must still be answered in the affirmative. Any instrument that is operated in the same manner over such a long period of time is obviously one that is fundamentally unchanged. Lack of change - either evolutionary or revolutionary - is a symptom of obsolescence. It is my experience that most undergraduate and graduate students today are not particularly interested in mastering the relatively primitive operating procedures of the TEMs that we use for teaching - or even the TEMs that are primarily research instruments. If we lose the interest of the next generation of potential microscopists, then the TEM will not only become obsolescent, it will become obsolete, and perhaps disappear from the commercial marketplace.

It is instructive to ask why operation of the TEM has remained unchanged for so long while its sister instrument, the SEM, has become completely computer controlled? The TEM was initially conceived to overcome the resolution limitations of the light microscope. The remnants of this original goal persist today, resulting in what I believe is an undue emphasis on the resolution of the instrument as being the most important factor. Thus, the instrument itself is the focus of TEM users. In contrast, the SEM, with its inherently poorer resolution, has never been seen as an instrument worth "mastering" (even though in its earliest renditions it was as complex a beast as the TEM). The SEM is regarded simply as a tool to be used to solve a problem. In the last decade or so, the SEM has undergone revolutions in terms of FEG operation, digital imaging, computer control and bulk electron-diffraction capabilities. Some of these revolutions have made the SEM a competitive instrument to the TEM, for as little as 20% of the cost. Nevertheless, its resolution (even in a run-of-the-mill SEM) has improved from 100 Å to <10 Å in twenty five years, and the usable specimen dimensions have increased from 10 mm stubs to 300 mm wafers. In contrast, despite years of emphasis on gaining better resolution in the TEM, it has only improved from ~3 Å to ~1 Å the last forty years and, over the same time, the specimen size has only increased from 2.3 mm to 3.05 mm. When you factor in the price differential, it is no wonder that the SEM is a more popular (and versatile) instrument, thriving in the commercial marketplace!

The idea that the TEM is a microscope while the SEM is 'relegated' to the status of a research tool has influenced the way that TEM has been taught to generations of students. The focus on the instrument alone has been compounded by the relative lack of commercial competition in the field, coupled with the high price of a TEM compared to a SEM. Because the users of TEMs have taken pride in acquiring such remarkable manual skills, the instrument development has not emphasized user-friendliness. Until the TEM is redesigned to run under the same conditions as the SEM, we will be unable to emphasize the education of students to *use* TEM for the solution of materials problems. We need to get beyond the idea that the TEM is an instrument worthy of study in its own right, and focus on its role as a tool for solving materials problems. For too long *mastery* of the instrument has taken precedence over the *application* of the instrument. ■

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Web Sites:
Material Safety Data Sheets on Chemicals

http://physchem.ox.ac.uk/MSDS/
Good site with lots of MSDS

http://msds.pdc.cornell.edu/issearch/msdssrch.htm
Great site allows you to search for over 325,000 MSDS

http://www.ps.uga.edu/ess/RightToKnow.html
Site with MSDS links

Http://www.ilpi.com/msds/index.chtml
Site with MSDS links

http://www.nwfsc.noaa.gov
Site allows you to search for MSDS

http://wren.musc.edu/docs2/safety.html