

Going cold: The future of electron microscopy

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Andrew Minor (Credit: Roy Kaltschmidt/Berkeley Lab)

Researchers use electron microscopy to produce high-resolution images at the atomic scale of everything from composite nanomaterials to single proteins. The technology provides invaluable information on the texture, chemistry, and structure of these materials. Research over the past few decades has focused on achieving higher resolutions: being able to image materials at progressively finer levels with more sensitivity and contrast. But what does the future hold for electron microscopy?

Andrew Minor is the facility director of the National Center for Electron Microscopy in Berkeley Lab's Molecular Foundry. Minor is also a member of the Materials Sciences Division, and a professor of materials science and engineering at UC Berkeley and has co-authored over 190 publications and received numerous awards and honors for his work. Minor's research group focuses on new methods using [electron microscopy](#) to study nanoscale structure and phenomena in materials.

Q. Is the future of electron microscopy about achieving even greater resolution or improving another facet of the technology?

A. Historically, [resolution](#) was the thing people were most interested in pushing, and that happened over the last 30 to 40 years to great effect. Electron microscopes can now reach half an angstrom resolution. That's half the width of a hydrogen atom, and a hydrogen atom is the smallest atom there is. There's not much to look at beyond that. So actual spatial resolution is not a huge driver anymore for most applications.

However, the big caveat is that this great resolution is really available only near room temperature. A lot of what we are interested in studying is not at room temperature, and there are big problems in reaching those types of resolutions if you go to very low temperatures or very high temperatures. My personal feeling is that the most impactful technological improvements will come from extending the resolution that we know and love at room temperature to other environments.

Q. What would high-resolution electron microscopy at lower temperatures enable?

A. One thing it would enable is getting better images of materials that are sensitive to the electron beam. There's this inherent tradeoff between

the fact that electrons interact very strongly with matter, but that also means they very easily damage the matter. A metal or a ceramic can withstand many electrons, what we call a high dose of electrons in an experiment. You can get very crisp images because you can send a lot of electrons through and really boost your signal to noise ratio. In the biological community, or even with a soft material like a polymer, the electrons themselves can and do very quickly cause damage to the structures. This limits your ability to image the material in a pristine or representative state.

One way the field has addressed this is by performing low-temperature microscopy, so-called cryoEM, where you're slightly limiting the damage to the material because things are more frozen in place and the damage doesn't evolve as fast. But when you go to low temperatures, because the whole rest of the microscope column is warm compared with the low temperature of the sample, your sample moves and changes its position. And when you're at high magnification it makes images blurry. So that's why I personally think, and here at Berkeley Lab we think, the solution to this inherent problem is to make the entire microscope cold. A big new concept that we're leading here is to develop a very low-temperature microscope that could go to one degree Kelvin. A lot of interesting materials exist only at those low temperatures.

Q. How far along are you in developing a cold microscope and what could it allow researchers to do?

A. We started the design with Laboratory Directed Research and Development Program support and have support from the Department of Energy through the Molecular Foundry to build a prototype superconducting magnet test system to confirm some aspects of our design. We also held a community meeting in January to look at the different science drivers and think about what could be done if you had

this beautiful resolution at low temperatures for novel materials. Whole aspects of condensed matter physics and solid-state physics really only exist in low temperatures. The most obvious one is superconductivity: most people know that superconductors exist only at low temperatures. You warm them up too much and that property goes away. A lot of properties are like that in what's called strongly correlated systems, or quantum materials for short. We haven't been able to examine with atomic resolution many of these interesting aspects of quantum materials because of the inherent problems of drift and stability in microscopes available now.

Another capability could be designing new materials or improving existing ones. In materials science we are interested in the correlation between structure and properties. Being able to examine that at the fundamental resolution of the material, like atoms, is a critical part of what goes into developing new materials.

Q. What might be other possibilities?

A. Exotic materials on faraway planets exist at cold temperatures. What can we learn about studying materials that only form at low temperatures? The low temperature microscope would also provide a high-vacuum environment, which would be ideal for looking closely at the surfaces of materials such as catalytic particles. Other things that would be of interest include the basic science of looking at structures when they are slow and frozen. A lot of processes are very fast at the atomic scale, like ions going back and forth in a battery. It's so fast that usually we can't capture it. Going cold would be one way to try to slow down processes to examine materials dynamically that are too fast to capture at room temperature.

I'm a materials scientist, so I gave you a lot of materials applications. But more broadly, the field of electron microscopy is impacting other fields,

such as the biological community, the earth sciences community, microelectronics, and drug discovery. Going to [low temperatures](#) is of interest in these fields because you'll get a better picture and better measurements and enable atomic resolution imaging in an environment that is important for many advanced technologies, like quantum computing.

More information: Thomas C. Pekin et al. Direct measurement of nanostructural change during in situ deformation of a bulk metallic glass, *Nature Communications* (2019). [DOI: 10.1038/s41467-019-10416-5](https://doi.org/10.1038/s41467-019-10416-5)

Ouliana Panova et al. Diffraction imaging of nanocrystalline structures in organic semiconductor molecular thin films, *Nature Materials* (2019). [DOI: 10.1038/s41563-019-0387-3](https://doi.org/10.1038/s41563-019-0387-3)

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