

metal sources, Levi Setti told us, is that "they produce usable ion beam currents with very little effort." Levi Setti's group had been using field-ionization sources to do transmission scanning microscopy with beams of hydrogen, helium and argon ions. The principle of such sources is similar to that of the liquid-metal sources, except that the ions are generated in a gas surrounding a needle point rather than on the point itself. The liquid-metal sources generate high ion-beam currents with such ease precisely because they are liquid. The supply of ions is continually renewed as metal flows toward the tip. These sources are in fact called "electrohydrodynamic field-ionization sources." The attainment of comparable currents with the gas field-ionization sources requires a "heroic effort," Levi Setti told us.

Nonetheless, Levi Setti concluded ten years ago that field-ionization gas sources could be made bright enough for high-resolution scanning microscopy. "Only the funds were lacking," he explained. The high-resolution instruments nearing completion at Hughes will use both liquid-metal and gas field-ionization sources. "We expect to get the best resolution (about 20 Å) with the light ions from the gas source," Levi Setti told us. The liquid-gallium source, although brighter, suffers more from chromatic aberration. The heavy ions emerge with an energy spread of 6 or 7 eV, limiting the focused spot size to a minimum of 50 to 100 Å.

In addition to the very-high-resolution Chicago-Hughes work, there is a worldwide effort to exploit liquid-metal ion sources for surface analysis and microfabrication in the 1000- to 5000-angstrom range. Groups at Hitachi, Osaka University and Nippon Telephone and Telegraph have developed Ga⁺ scanning ion microscopes. Orloff and Swanson have built gas-phase and liquid-metal scanning ion microscopes for surface analysis and microscopy in the 2000- to 5000-Å range.

Recent results obtained by the Chicago group with its 1000-Å microscope were reported in January at the US-

Japan Seminar on Charged Particle Penetration Phenomena in Honolulu. Since the Chicago-Hughes collaboration was formed in 1980, this Chicago microscope, which is very similar to the low-resolution instrument that Seliger and his colleagues had built independently, has been employing a liquid gallium ion source produced at Hughes.

The Chicago group has found that the intensity of the secondary-electron ion signals from brass and iron samples illuminated by 60-keV Ga⁺ ions is a very sensitive function of the beam direction relative to the crystallographic orientation of the sample. They attribute this effect to ion channeling (see PHYSICS TODAY, May 1980, page 17). When the incident beam direction falls within a critical channeling angle, the gallium ions can pass relatively unhindered between lattice planes. In this lower-density interplane region the ions lose less energy per unit length than they would if they entered at a random angle. The channeled ions can then penetrate the sample to depths of more than five times the normal ion penetration depth of about 200 Å. The reduced energy loss of such channeled ions suppresses the emission of secondary electrons and ions.

In this way striking contrast is achieved between adjacent regions of different crystallographic orientation. Though he had expected some channeling effect, Levi Setti told us that he was stunned by the quality and magnitude of the contrasts exhibited by the micrographs. "They demonstrate clearly that we can detect dislocations in very pure crystals," he explained. The present microscopes are still limited by resolution, but with the high-resolution microscope he hopes to be able to detect single crystalline dislocations.

Secondary-electron images have exhibited contrasts of more than 3 to 1 across crystal boundaries. As samples are rotated under the scanning beam, contrasting regions can be made to reverse relative brightness. Scanning electron microscopes can also see channeling effects, but the resulting contrasts do not generally exceed 5%. The Chicago group has been able to see

laminar arrays of "twinning" dislocations resulting from impact shock in iron meteorites. Scanning ion micrographs of integrated circuits exhibit much better contrast, Levi Setti asserts, than one sees in scanning-electron micrographs. He expects that the scanning ion microscopes will become a standard instrument for the routine examination of crystal imperfections in metallurgy and microelectronic fabrication.

In addition to the channeling-induced contrast between differently oriented crystalline regions of the same material, the scanning ion micrographs exhibit very pronounced contrasts between chemically different areas of a sample. This suggests that one could use the instrument for microscopic elemental mapping even without secondary-ion mass spectrometry. Levi Setti also told us that his secondary-electron micrographs have clearly delineated magnetic domain boundaries in ferromagnetic samples.

While producing high-quality micrographs with 1000-Å resolution of a wide variety of samples—from *Drosophila* eyes to meteorites—the Chicago-Hughes collaborators have been exploiting their low-resolution microscopes to determine the optimum design parameters for their high-resolution scanning ion microscope. Examining the energy spectra of gallium ions as a function of source current, for example, they have discovered that there exists an optimum current that minimizes the effects of chromatic aberration, which is the limiting factor determining the ion microscope's resolution.

The optics required for a high-resolution ion microscope are trickier than what one needs for a scanning electron microscope. The Chicago-Hughes collaboration's calculations lead them to expect that the two-lens electrostatic focusing system of their second-generation microscope will by the end of this year achieve a resolution as good as that of the best scanning electron microscopes. But, Levi Setti cautions, one can't be certain until the instrument is completed. —BMS □

Bevalac accelerates uranium

The Bevalac at the Lawrence Berkeley Lab is now accelerating uranium ions. This photographic emulsion shows the last half millimeter of track for three uranium ions accelerated to 150 MeV/nucleon. The bottom nucleus is seen to split into fragments. With its new injector for the Superhilac and a new Bevatron vacuum system, the Bevalac (as one calls the tandem system of Superhilac and Bevatron) is now capable of accelerating uranium to 900 MeV/nucleon.

