letters

Microfabrication

I want to comment on the use of ion beams in Alec Broers's article "High resolution systems for microfabrication," November, page 38:

▶ Some authors claim that ions are orders of magnitude more efficient in exposing resists as PMMA. This is only correct if the exposure dose is measured in charge delivered per cm^2.

▶ If the dose is given in the more appropriate unit energy delivered per volume element of resist, then our experiments at GSI show that ion beams are exactly as effective as electrons or x rays. This remarkable result can probably be explained by the fact that in all three cases electrons are the particles that ultimately depolymerize the resist. (At least if 200-keV ions not heavier than neon are considered).

▶ We see no reason why only electrostatic systems should be used for ion-beam systems. If focussing power is concerned, magnetic multipole lenses are superior to electrostatic ones for high-energy ions.

▶ In contrast to Broers's opinion, charge repulsion effects will be much less severe for ion-beam systems. We, for example, need 10^{12} 750-keV argon ions per cm^2 to expose PMMA compared to about 3×10^{14} 20-keV electrons to do the same job. If a focal distance of 50 mm is assumed for an electron beam and 100 mm for the ion beam (a value we achieve) beam blow up by charge repulsion is about 50 times smaller for the ion beam. This "stiffer" ion beam is also much less influenced by a (much less) charged resist surface.

▶ Microstructures can also be made by projecting an extended ion beam through a mask on a resist with surprisingly low mask damage.

▶ An unique advantage of (especially heavy) ion beams is that not only conventional resists but also any other material shows enhanced etching after exposures with ion doses of between 10^{11} to 10^{14} ions/cm^2.

▶ If costs for submicron mask projection systems are concerned, ion accelerators in the necessary energy range are much less expensive than the competing electron synchrotrons for x-ray lithography. In addition those ion accelerators generate ion currents sufficient to expose about 1 m^2 PMMA per second.

In conclusion we can only underline Broers's opinion that ion beams are a very promising tool for future microfabrication systems.

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The author comments: In their letter B. E. Fischer and R. Spohr strongly support the potential of high-energy ion beams for lithography. I am in general agreement with this opinion, but feel there are still areas where great progress will have to be made before, in particular, ion-beam writing systems can demonstrate feasibility for VLSL lithography. Contact printing with ions would provide adequate speed, but the difficulty of maintaining adequate dimensional accuracy between mask and wafer for micron dimensions is the same as it is for any contact printing method whether using ultraviolet light, electrons or ions. Increased exposure speed, lack of proximity effect and high resolution are advantages of using ions.

The major problem I foresee for ion-beam writing systems is that of building an adequate deflection and focusing system. This is connected with my comment about electrostatic rather than magnetic fields. For future VLSI, a beam size of 0.25 micron will be needed and, assuming electronic scanning is used, this beam will have to be deflected over a field of up to 1 cm × 1 cm. To achieve this performance with electron beams, it has been necessary to superimpose deflection and focusing fields in order to cancel off-axis aberrations. A double deflection coil with no more than a few turns, and sometimes only single wires, is placed inside the axially symmetric magnetic field of a magnetic lens using ferrite pole-pieces. The small number of turns in the deflection coil reduces induction to a minimum and enables the coil to be fabricated to the required tolerances. The ferrite pole-pieces ensure that errors due to eddy currents are kept to a minimum. Both these precautions have been found to be essential in order even to approach the required operating speed. Further improvement is still being sought. Such a system could not deflect and focus 750-keV argon ions because the fields would have to be about 1500 times greater, vastly exceeding the driving capabilities of the

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deflection electronics, the thermal capacity of the deflection coil, and the saturation flux of the ferrite pole-pieces. It is difficult at present to see how multiple lenses could be used similarly in conjunction with a deflection system to cancel off-axis aberrations, but to my knowledge, this has never been investigated. Presumably, deflection would have to be electrostatic because a field of tens of kilogauss would be needed to deflect keV argon ions, and it would not be possible to modulate such a field with adequate bandwidth.

A possible way to avoid the large-field deflection problem altogether would be to only deflect the beam over a small distance in one direction and move the sample mechanically to provide the other scan direction as is done in the EBES electron-beam system.

In some ways, the deflection and focusing problem for ions is similar to—and perhaps no more serious than—that which confronted workers and electron beam lithography in the early 1960's, but it nonetheless appears formidable at the present time.

The point raised on the definition of resist sensitivity has arisen frequently. I tend to support the contention that a definition of charge per unit area is more useful in this technological science than the more academically correct definition of charge per unit volume. In general, one is interested in the efficiency with which a given radiation can expose thin layers of resist, which in practice are of similar thickness. As pointed out, ions are more efficient because their energy is more completely dissipated in the resist rather than in the substrate, as it is with electrons.

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Grantsmanship in advertising

In the December issue, as in previous issues, advertisements (pages 92–106) have appeared for senior faculty with the words "Proven ability to generate grant support is a requirement," while nothing is said about teaching experience or competence other than that "most" faculty "take a strong interest" in teaching programs.

Such advertisements in effect set new standards for faculty procurement and are ultimately influential in determining qualifications and obligations of faculty and the quality of academic teaching and research. Surely such advertisements warrant discussion before they create new professional norms.

A number of issues are involved. First, and perhaps foremost, is the obvious down-grading of teaching. Indeed, such an advertisement closes the door at once to anyone who is primarily concerned with teaching.

It also closes the door to anyone whose research requires little or no grant support. Conversely, it tends to put a premium on research that is costly and requires, or has obtained, large grant support in the past. This is likely to mean that the research involved is in a fashionable field and of stereotyped character long supported by federal agencies. It is in effect an announcement that anyone interested in an unconventional field, or in launching something unconventional, or in changing fields need not apply. In short, it tends to bar the innovative, the unconventional in favor of the familiar, the sure-fire, in the name of research!

Is it too much to infer that an advertisement for grant-bringing faculty such as we are discussing is really interested neither in teaching nor in truly original research, but primarily in the grant funds themselves!

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More on atomic resonances

The interesting article on atomic resonances by Manfred Biondi, Arvid Herzenberg and Chris Kuyatt (October, page 44) kindly credits me with a remark that is actually due to the late Robert L. Platzman, and with other incidents I don't recall. I'd like to draw attention to Platzman's seminal influence on the extraordinary outpouring of physics that followed George Schulz's discovery of the 19-eV helium resonance and to add some other footnotes to the article's description of those events.

Franck and Grotrian's paper, to which Platzman drew my attention, identified the critical factor controlling the electron affinity of atoms and molecules, namely, the occurrence of unfilled electron shells in their structure. This assessment of the affinity phenomenon has held true for 60 years. This paper also remarked, offhandedly but very farsightedly, that any electronic excitation provides unfilled shells and thereby the opportunity for electron attachment; hence follow the "Feshbach resonances" in atoms and molecules.

James Franck transmitted to Platzman his drive toward providing broad outlines and interpretations of the electric, magnetic and spectral behavior of physicochemical systems. Thus Platzman stressed in the 1950's our ignorance of the spectral distributions of oscillator strength, that is, of the dielectric properties of matter over 2–3 decades of the spectrum in the far ultraviolet and soft x-ray ranges. He also anticipated that synchrotron light sources would serve to fill this gap. Efforts to stimulate work in

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