

XIX. SUBMICRON STRUCTURE FABRICATION AND RESEARCH

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1. OPERATION OF SUBMICRON STRUCTURES LABORATORY

Joint Services Electronics Program (Contracts DAAG29-78-C-0020 and
DAAG29-80-C-0104)

M.I.T. Sloan Fund for Basic Research

John Melngailis, Henry I. Smith

The goals of the Submicron Structures Laboratory are to develop methods of fabricating surface structures of nanometer to micrometer linewidths and to use these structures in a variety of research projects.

Since May 1979, when the Submicron Structures Laboratory was inaugurated within the Research Laboratory of Electronics, all of the equipment needed for fabrication has been operating and in heavy use. Support personnel has been expanded from one technician to three. A scanning electron microscope has been bought and put into operation. The main projects of the laboratory are outlined below. In addition, the laboratory has served as a resource for numerous research projects of neighboring laboratories and has participated in smaller collaborative projects. Some examples:

- a. P.F. Liao of Bell Laboratories visited our laboratory for two weeks and fabricated a grid of silver dots with 0.3 μm period in two orthogonal directions. This permitted the first observation and study of the

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surface-enhanced Raman effect on artificially produced particles of controlled size.¹

- b. R.M. Fastow fabricated thermal desorption arrays for the molecular microscope as a B.S. physics thesis with Prof. J.G. King.
- c. D.H. Liang has fabricated micron-sized contacts for measuring the electrical currents in a single nerve cell. The design and production of this structure was carried out in the Submicron Structures Laboratory. This nerve cell project is being done in collaboration with Prof. R.G. Mark of the E.E.C.S. Department, Dr. William Barry of the Peter Bent Brigham Hospital and S. Frankel, formerly of Harvard.
- d. Square-wave profile gratings of 0.3 μm to 1 μm period have been fabricated by H. von Kanel for research on liquid crystal alignment. This work is in collaboration with Prof. J.D. Litster.
- e. Surface-acoustic-wave structures, which consist of gratings on a YZ LiNbO_3 parallel-faced slab, have been fabricated. The aim is to exploit the recently discovered, very efficient, surface-wave-to-bulk-plate-mode coupling in gratings to make low-loss narrow-band filters.^{2,3} This work is done in collaboration with Prof. H.A. Haus, A. Lattes, and E.M. Garber.

Publications and References

1. P.F. Liao, J.G. Bergman, D.S. Chemla, A. Wokaun, J. Melngailis, A.M. Hawryluk, and N.P. Economou, "Surface Enhanced Raman Scattering from Microlithographic Silver Particle Surfaces," submitted to Phys. Rev. Letters.
2. J. Melngailis, H.A. Haus, and A. Lattes, "Efficient Conversion of Surface Acoustic Waves in Shallow Gratings to Bulk Plate Modes," Appl. Phys. Lett. 35, 324 (1979).
3. H.A. Haus, A. Lattes, and J. Melngailis, "Grating Coupling between Surface Acoustic Waves and Plate Modes," IEEE Trans. on Sonics and Ultrasonics, SU-27, 258-266 (1980).
4. H.I. Smith, "The Impact of Submicrometer Structures on Future Integrated Electronics," EASCON '79 Record, pp. 296-297.

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2. DEVELOPMENT OF MICROFABRICATION TECHNIQUES

Joint Services Electronics Program (Contracts DAAG29-78-C-0020 and
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U.S. Navy — Office of Naval Research (Contract N00014-79-C-0908)

Andrew M. Hawryluk, John Melngailis, Henry I. Smith

Techniques are being developed for the fabrication of artificial microstructures having minimum feature sizes in the range of 100 \AA to $1 \text{ }\mu\text{m}$. Methods that are applicable to periodic and quasi-periodic structures are emphasized, including: holographic lithography, spatial-periodic division, and x-ray replication of "shadowed" relief gratings. These techniques were initiated at M.I.T. Lincoln Laboratory. Starting with holographically exposed patterns we have produced grating masks and have x-ray-replicated linewidths as fine as 500 \AA . Structures of 500 \AA linewidth were etched into SiO_2 substrates by reactive ion etching. In some cases, sawtooth and square-wave profile relief gratings in polyimide were obliquely shadowed with heavy elements to yield high-contrast x-ray masks, which were then x-ray replicated. We hope to achieve 100 \AA linewidths with this or similar techniques. To expose gratings with spatial periods below 1000 \AA we will use the near-field diffraction pattern of a grating of narrow slits, so-called "spatial-period division." Techniques for fabricating a 2000 \AA period grating of 500 \AA wide slits in thick gold, to serve as the parent grating, are being developed.

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3. X-RAY LENSES AND GRATINGS

Lawrence Livermore Laboratory (Subcontract 206-92-09)
Joint Services Electronics Program (Contracts DAAG29-78-C-0020 and
DAAG29-80-C-0104)

U.S. Navy – Office of Naval Research (Contract N00014-79-C-0908)

Andrew M. Hawryluk, John Melngailis, Henry I. Smith

Starting with a mask generated by scanning electron-beam lithography, Fresnel zone plates are being fabricated to be used as x-ray lenses. This work is currently being done partly at Lincoln Laboratory and partly at the Submicron Structures Laboratory. So far, a number of zone plate patterns with 0.3 μm minimum linewidth and 0.7 to 1.0 μm gold thickness have been fabricated on a glass substrate. X-ray replication and microplating techniques needed to achieve these structures have been developed. Techniques for removing the glass to leave a free-standing structure are being refined.

A 0.3 μm period grating of 0.7 μm thick gold lines has been fabricated on a 0.7 μm thick polyimide film over an area of 1 cm^2 . This will serve as a transmission grating for x-rays and is being tested at Lawrence Livermore Laboratory.

Very thick ($\sim 100 \mu\text{m}$) zone plates with 5 μm minimum zone width for so-called "coded imaging" are being fabricated in collaboration with the Lawrence Livermore Laboratory. For this fabrication a procedure for directional reactive ion etching of organic films with oxygen was employed.

Publications

H.I. Smith, "Equivalent Data Rate of X-Ray Lithography Systems," Proc. 9th International Conference, Electron and Ion Beam Science and Technology, St. Louis, Missouri, May 1980 (in press).

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4. GRAPHOEPIITAXY

U.S. Navy -- Office of Naval Research (Contract N00014-79-C-0908)

U.S. Department of Energy (Contract DE-AC02-80-E10179)

Stephane S. Dana, Krikor A. Bezdjian, Shlomo Rotter, Henry I. Smith

The graphoepitaxy work has two main goals: to understand the fundamental mechanisms of orientation by artificial steps on substrates and to produce uniformly oriented semiconductor films on conducting substrates appropriate for solar cells. Silicon crystallites have been nucleated on 3000 Å period grating structures using chemical vapor deposition. The nuclei appear to be oriented and to grow primarily in the bottoms of the grooves where they are confined by the vertical sidewalls. To further study the orientation mechanisms on relief gratings, NaCl crystals have been grown from an aqueous solution. Orientation due to the grating is observed, and experiments are being carried out to determine the conditions needed for this.

Fine gratings on conducting molybdenum substrates have been successfully prepared by electron-beam evaporation and lift-off. Attempts will be made to grow InP and GaAs on these substrates by liquid-phase epitaxy. In addition, liquid-phase epitaxy has been carried out on patterned lead tin telluride substrates. The pattern consists of square islands produced by crossing two 3.8 μm period gratings. The morphology of the lead tin telluride layers grown on the patterned substrates improved substantially. The electrical characteristics of these "homographoepitaxial" layers will be studied.

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5. ONE-DIMENSIONAL CONDUCTION IN SILICON

Joint Services Electronics Program (Contracts DAAG29-78-C-0020 and
DAAG29-80-C-0104)

Robert F. Kwasnick, Marc A. Kastner, John Melngailis

A field-effect transistor-type structure has been fabricated in which the conduction path under the gate electrode is divided into sharp ridges. The tips of the ridges on a preliminary grating have 30-nm radius. With this structure, effects due to electron localization in the one-dimensional conductors are expected to be observed. One structure has been tested as a function of temperature. Preliminary results resemble the behavior of an MOS transistor.

6. REACTIVE ION ETCHING

Harkness Foundation

Joint Services Electronics Program (Contracts DAAG29-78-C-0020 and
DAAG29-80-C-0104)

Christopher M. Horwitz

The reactive ion-etching rates of Al, Cr, Si, SiO₂, and MgF₂ have been studied for various gas compositions, pressures, and bias voltages. The aim of this work is to fabricate highly conducting metal grids of about 0.75 μm period and narrow linewidth to serve as optical filters or as contacts on solar cells, and to develop random arrays of pointed conical structures, with an average spacing of less than 0.1 μm, to serve as optically nonreflecting structures. For both of these applications very directional etching is needed, which can only be achieved with a low mask-to-substrate etch-rate ratio. Several important results have been achieved so far: the SiO₂/Si etch-rate ratio has been controlled between 8.6 and 0.02. The Al/MgF₂ etch-rate ratio in Cl₂ mixtures can be as high as 130 provided care is taken with vacuum techniques. For other gas mixtures Al can be an excellent mask. For example, an etch-rate ratio for Si/Al of greater than 3000 has been observed.