Part I Solid State Physics, Electronics and Optics

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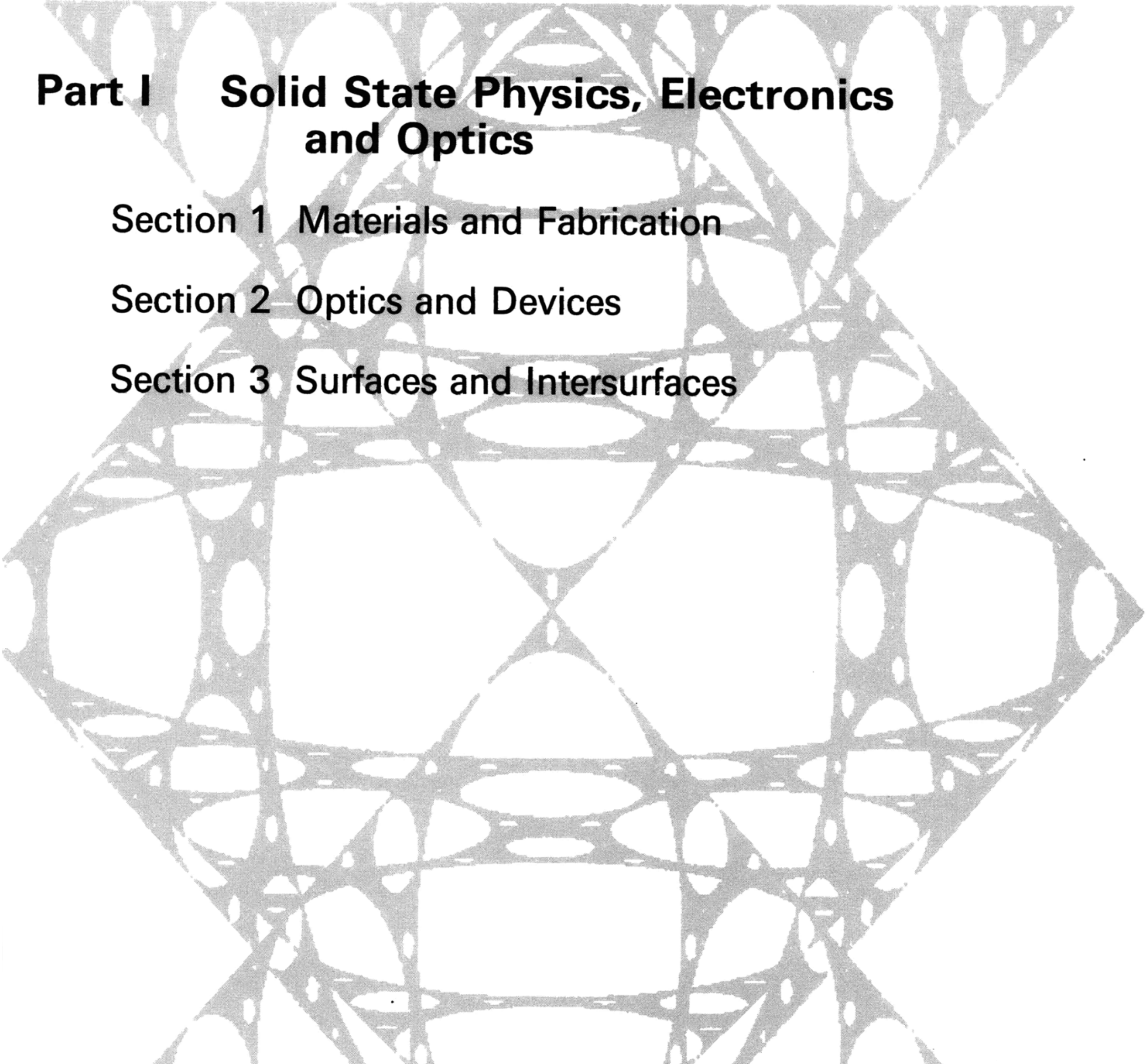

Section 1 Materials and Fabrication

Chapter 1. Submicron Structures Technology and Research

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1.1 Submicron Structures Laboratory

The Submicron Structures Laboratory at MIT develops techniques for fabricating surface structures with linewidths in the range from nanometers to micrometers, and uses these structures in a variety of research projects. These projects of the laboratory, which are described briefly below, fall into four major categories: development of submicron and nanometer fabrication technology; nanometer and quantum-effect electronics; crystalline films on amorphous and non-lattice-matching substrates; and periodic structures for x-ray optics, spectroscopy and atomic interferometry.

1.2 Microfabrication at Linewidths of 100nm and Below

Sponsors

Joint Services Electronics Program
(Contracts DAAL03-86-K-0002 and DAAL03-89-C-0001)
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Project Staff

Erik H. Anderson, Martin Burkhardt, James M. Carter, William Chu, Kathleen Early, Yao-Ching Ku, Hui Meng Quek, Alberto Moel, Dr. Mark L. Schattenburg, Professor Henry I. Smith, Anthony T. Yen

A variety of techniques for fabricating structures with characteristic dimensions of 0.1 μm (100 nm) and below are investigated. These include: x-ray nanolithography, holographic lithography, achromatic holographic lithography, electron-beam lithography, focused-ion-beam lithography, reactive-ion etching, electroplating, and liftoff. Development of such techniques is essential if we are to explore the rich field of research applica-

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tions in the deep-submicron and nanometer domains.

X-ray nanolithography is of special interest because it can provide high throughput and broad process latitude at linewidths of 100 nm and below, something that cannot be achieved with scanning-electron-beam or focused-ion-beam lithography alone. We are developing a new generation of x-ray masks made from inorganic membranes (Si, Si_3N_4, and SiC) in order to eliminate pattern distortion. To achieve multiple-mask alignment, compatible with 50 nm linewidths, we will fix the mask-sample gap at 4 μm using recessed sapphire ball bearings, translate the mask piezoelectrically, and detect alignment to < 10 nm by a dual-grating diffraction scheme. Phase-shifting and transform x-ray masks (i.e., in-line x-ray holography) may permit us to achieve sub-50 nm linewidths at gaps of several microns. In previous studies we showed that for one-dimensional patterns a pi-phase-shifting mask improves process latitude by increasing the irradiance slope at feature edges. This year, we have investigated two-dimensional patterns and found similar results.

In studies carried out at Cornell University with an e-beam lithography system, and here at MIT using focused-ion-beam lithography (FIBL), we compared the two methods for fabricating x-ray masks having minimum features of 50 nm. The FIBL approach proved more effective because of greater process latitude and simplicity. This is illustrated in figure 1. Quantum-effect-device patterns were created and will soon be tested on GaAlAs/GaAs substrates.

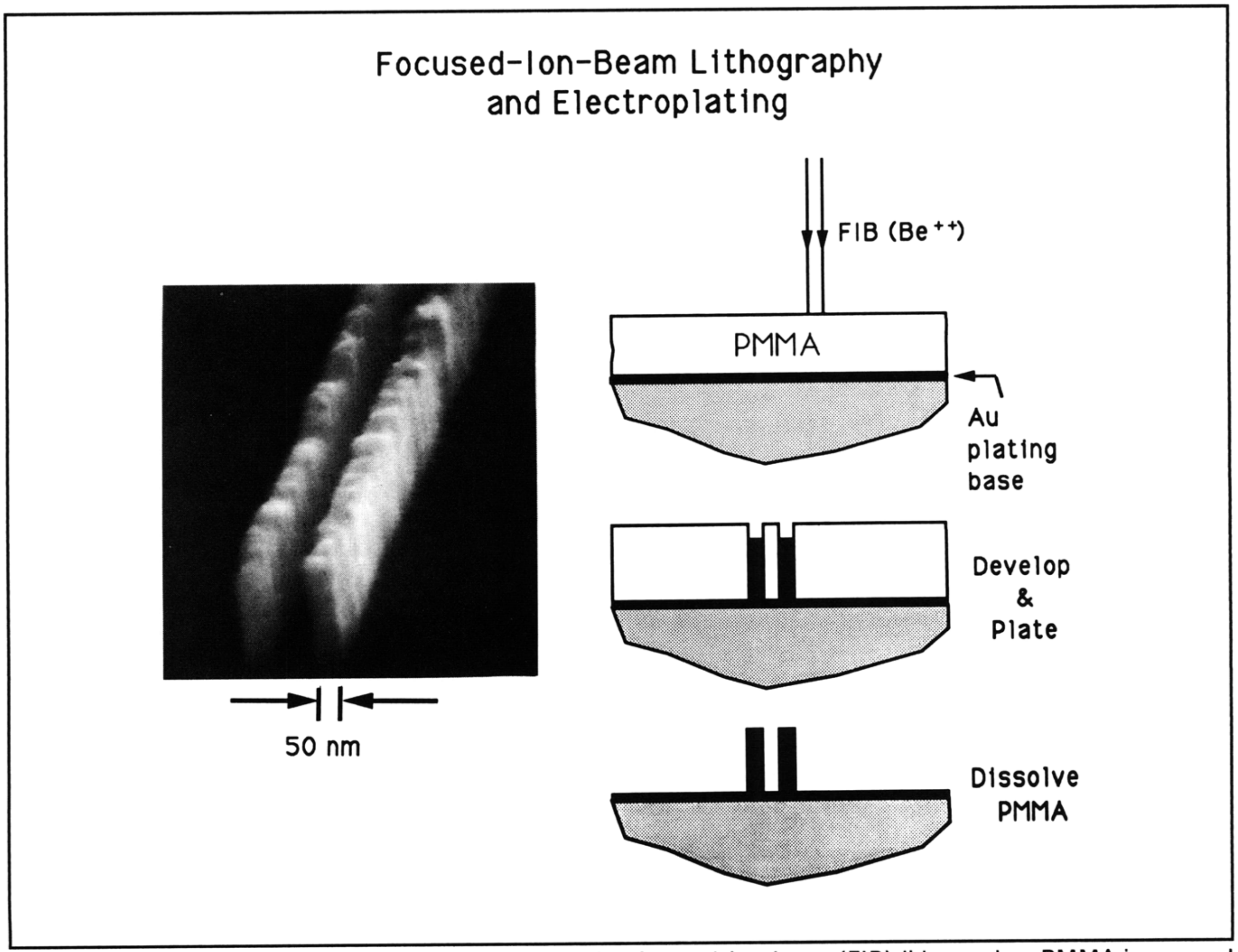

Figure 1. Fabrication of x-ray nanolithography mask using focused-ion-beam (FIB) lithography. PMMA is exposed with a Be^{++} beam at 200 keV, developed, and then gold electroplating completes the x-ray mask.

X-ray masks were made from crystallographic templates etched in (110) Si. The resulting gratings replicated in PMMA had linewidths of 40 nm. These patterns were then reactive-ion etched in SiO_2 and used in studies of grain growth of ultrathin films.

A feedback-stabilized holographic system was completed and used to produce high contrast gratings of 200 nm period over areas several cm in diameter. This technique was used to produce grating structures for permeable-base-transistor circuits, x-ray interferometry, and for x-ray masks. Such masks are subsequently used to produce devices for studies of quantum-effect electronics. A similar feedback stabilization method was used with the achromatic holographic lithography to yield 120 nm-period patterns.

1.3 Improved Mask Technology For X-Ray Lithography

Sponsors

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Project Staff

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In order to utilize x-ray lithography in the fabrication of submicron integrated electronics, distortion in the x-ray mask must be eliminated. Distortion can arise from stress in the absorber, which is usually gold or tungsten. Tungsten is preferred because it is a closer match in thermal expansion to Si, and other materials used as mask membranes. However, W is usually under high stress when deposited by evaporation or sputtering. Earlier, we demonstrated that tensile stress in W can be compensated by ion implantation. Stress compensation occurs because the implantation into the top 10 nm of the W film causes a compressive stress which in turn produces a torque to compensate the torque produced by the native tensile stress.

This year, we demonstrated that for a given type of substrate, zero stress (i.e., less than 5×10^7 dynes/cm^2) can be achieved by controlling the sputtering pressure to within one-tenth of a millitorr. We also investigated the use of a fiber optic interferometer to monitor mask distortion during sputter deposition, in an effort to develop a feedback system for control of film stress. At present, we are investigating more sensitive means of measuring stress in situ during deposition, and will measure in-plane distortion in large-area membranes using a diffractive optical technique.

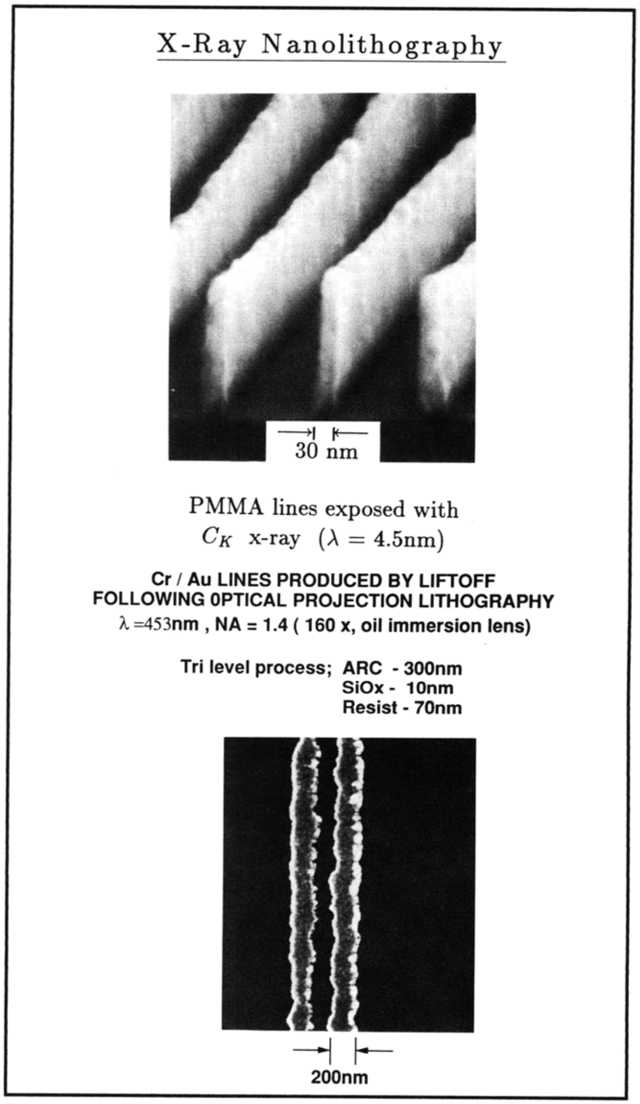

Figure 2. Electron micrographs of metal lines obtained by a tri-level process that consisted of: optical projection exposure and development; etching of a SiO_x intermediate layer; etching of the antireflection coating; a) single metal line, b) pair of adjacent metal lines.

1.4 Optical Projection Lithography Using Lenses of High Numerical Aperture

Sponsor

Joint Service Electronics Program
(Contracts DAAL03-86-K-0002 and DAAL03-89-C-0001)

Project Staff

James M. Carter, Dr. Hiroaki Kawata, Professor Henry I. Smith, Anthony T. Yen

We have studied the characteristics and limitations of optical projection lithography using high numerical-aperture (NA) optical microscopy lenses. With oil-immersion, NA's as large as 1.4 were realized, and linewidths as fine as 140 nm were achieved in 70 nm-thick commercial photoresist films, using illumination of wavelength λ = 453 nm. Previous researchers have also obtained deep-submicron linewidths using high NA lenses.

The new elements in our work were: 1) use of a photoresist-compatible oil to achieve NA = 1.4; 2) use of modern antireflection coatings (ARC) and tri-level processing to circumvent the problem of substrate back-reflection; 3) use of NA > 1 optical-projection to make masks for x-ray lithography, and the x-ray replication of such masks; 4) alignment of several exposure fields via step-and-repeat, using a moiré alignment technique.

Our motivation in pursuing this work was to explore the limits of high-NA optical projection, to develop a simple, quick-turn-around method of making sub-quarter-micron-linewidth x-ray masks, and to model the exposure field that would be obtained at λ = 193 nm and NA = 0.6. Using the formula for minimum feature width, $W_{min} = k\lambda/NA$, we found that with an ARC and careful focusing one can work at k = 0.43. Focusing and alignment were done by projecting the reticle image onto the resist with yellow light, which does not expose the resist. For exposure, the yellow filter was removed and a narrow-band blue filter (λ = 453 nm) inserted. Exposure time and linewidth were highly dependent on proximity of other features, a manifestation of the small process latitude of optical projection lithography when pushed to its limits.

X-ray masks with minimum features of 300 nm were made and successfully replicated.

To a first approximation, the aerial image we obtained at λ = 453 nm and NA = 1.4 is equivalent to the image one would obtain with λ = 193 nm (ArF laser) and NA = 0.6, since the ratio λ/NA is the same in both cases. Of course, depth of focus would be larger by the factor of 1.5 for λ = 193 nm, NA = 0.6. (Depth of focus does not scale as NA^2 with oil immersion.) Our results indicate that the very limited process latitude of optical projection lithography when pushed to its limits, and the presence of coherence effects, make application to quarter-micron manufacturing highly problematic.

1.5 Studies of Electronic Conduction In One-Dimensional Semiconductor Devices

Sponsors

Joint Services Electronics Program
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Project Staff

Professor Dimitri A. Antoniadis, Stuart B. Field, Professor Marc A. Kastner, Jerome C. Licini, Udi Meirav, Samuel L. Park, John H.F. Scott-Thomas, Professor Henry I. Smith

Sophisticated processing techniques and advanced lithography have allowed us to enter what we believe is a fundamentally new regime in the study of electronic conduction in one-dimensional systems. A slotted-gate MOSFET structure (figure 3) was used to produce an electron gas at the Si/SiO_2 interface beneath the gap in the lower-gate. This was done by biasing the upper gate positively, while keeping the slotted gate just below threshold. Fringing fields created by the lower gate confined the electron gas to a width substantially narrower (~25 nm) than the distance separating the two halves of the slotted gate (~70 nm). The slotted gate was produced using x-ray nanolithography and liftoff. It was composed of refractory metals to allow a subsequent high temperature anneal. This anneal removed damage created by the e-beam evaporation of the refractory metal, so that the electron gas had a mobility of 15,000 cm^2/V-sec at 4.2K.

The electrical conductance of the 1-D gas was measured as a function of the gate voltage for temperature less than 1K, and a surprising series of periodic oscillations were seen in the conductance (figure 4). Changing the gate voltage can be thought of as changing the number of electrons per unit length of electron gas. The oscillations then reflect a periodic change in the activation energy of the electron gas as the electron density is changed. From computer simulations of the device, we know the oscillations are seen most strongly when the electron gas is in the dynamically one-dimensional regime. That is, the electrons are in the lowest quantum energy level of the potential well created by the fringing fields of the slotted gate.

It is known that a one-dimensional electron gas in a periodic potential (created by the Si atoms in this case) will undergo a spatial distortion to reduce its energy, forming a "change density wave" (CDW). A CDW would be pinned by impurities in the device. As the periodicity of the CDW is changed

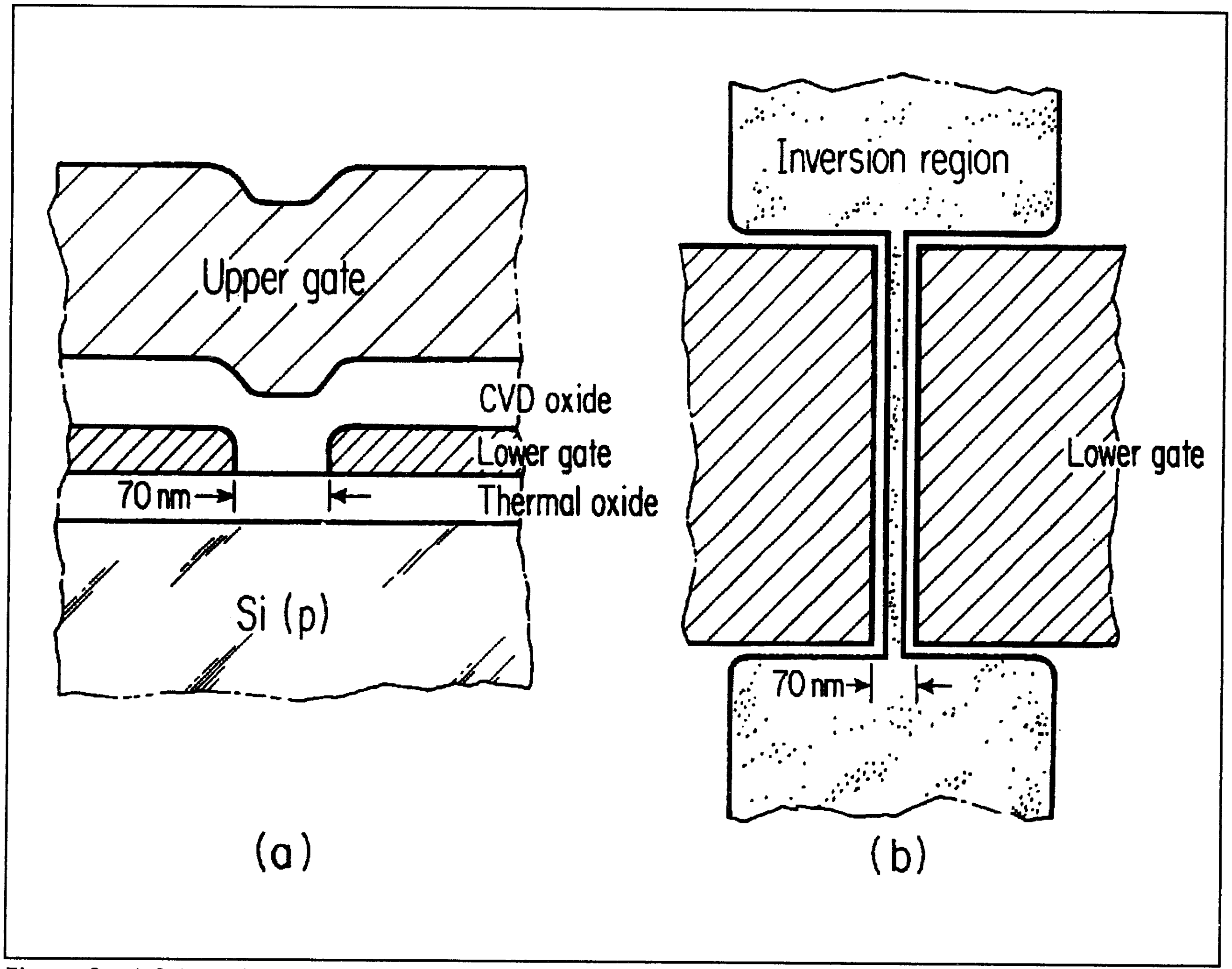

Figure 3. a) Schematic cross section and b) top view of the slotted-gate device. The inversion layer, formed by the positively biased upper gate is confined by the lower gate. The thermal oxide and refractory metal lower gate are both 30 nm thick, and the chemical vapor deposition oxide is 45 nm thick. The width of the narrow inversion layer is exaggerated in b).

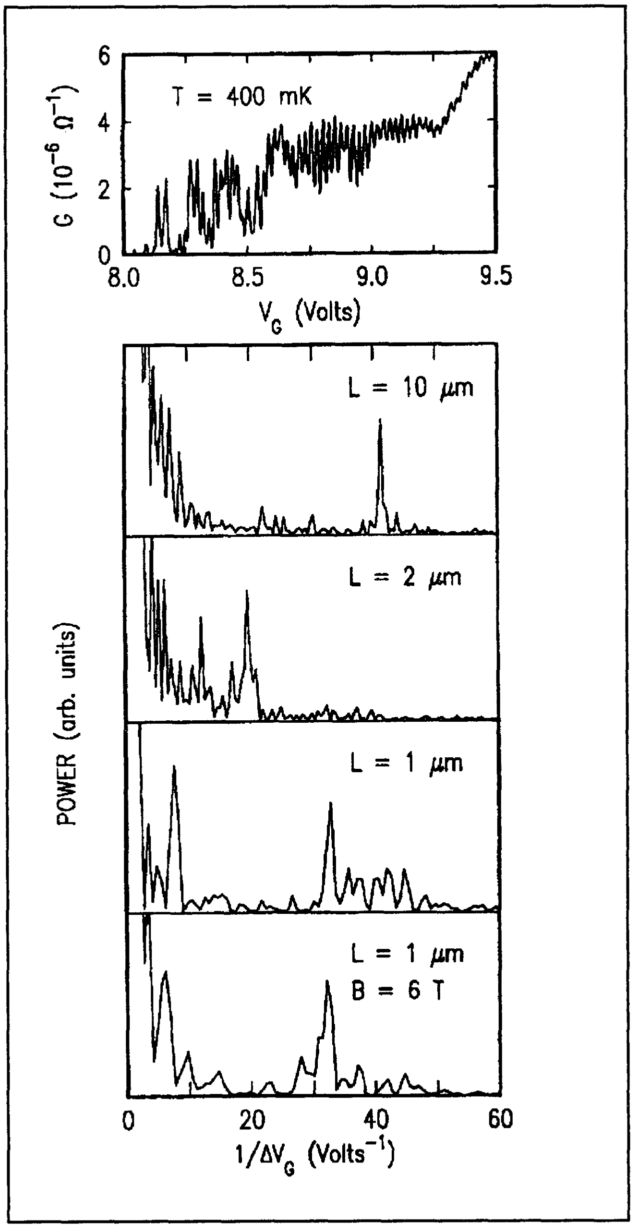

Figure 4. Top panel: G vs V_G for a 10-μm-long inversion layer. Next three panels: Fourier power spectra of the data of the top panel and for 2-μm and 1-μm-long channels. Bottom panel: Fourier spectrum for the 1-μm-long channel in a magnetic field.

(by changing the electron density), it would in turn be strongly pinned and weakly pinned by the impurities – resulting in an oscillatory behavior of the conductance with electron density. The period of the oscillations varies randomly from device to device, with no dependence on length, and the period changes in the same device when it is heated to above 30K. This strongly suggests mobile impurity atoms are doing the pinning.

It should be stressed that these oscillations are seen with no magnetic field, implying that the phenomenon is fundamentally different from phenomena requiring Landau quantization (such as the Quantum Hall Effect). Also, the effect seems to require a many-body theory (i.e., one incorporating electron-electron interactions).

1.6 Surface Superlattice Formation In Silicon Inversion Layers Using 0.2μm-Period Grating-Gate Field-Effect Transistors

Sponsors

Joint Services Electronics Program
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U.S. Air Force - Office of Scientific Research
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Project Staff

Professor Dimitri A. Antoniadis, Phillip F. Bagwell, Professor Marc A. Kastner, Professor Terry P. Orlando, Professor Henry I. Smith, Anthony T. Yen

We have been studying distinctly quantum mechanical effects in electrical conduction using the silicon grating-gate field-effect transistor (GGFET). The Si GGFET is a dual stacked-gate MOS type structure in which the gate closest to the inversion layer is a 200 nm-period grating, made of refractory metal. A SiO_2 insulating layer separates the grating gate and the inversion layer from a continuous aluminum upper gate. Two types of electronic devices are possible in this geometry: 1) a lateral surface superlattice (LSSL) in which carrier conduction is perpendicular to the grating lines; and 2) a quasi-one-dimensional (Q1D) GGFET which confines carriers to narrow strips beneath the grating lines in multiple parallel quantum wires.

In the case of the LSSL, the dual gate allows independent control of the average electron density in the inversion layer and the strength of the periodic modulation. This gives the LSSL GGFET an advantage over grown superlattices in which both the density and strength of the periodic modulation are fixed. In Q1D devices the dual gate allows narrow inversion regions to be formed between gate wires. This permits easy control of the inversion layer width. The multiple parallel quantum wires of the Q1D GGFET also appear to have an advantage over single wire devices in efforts to observe Q1D subbands in the conductance, since the multiple wires average over defects and universal conductance fluctuations in each separate wire.

We fabricate the 200 nm-period grating gate using x-ray nanolithography and liftoff. Contact pads to the grating gate are made using deep-UV lithography. Damage to the gate oxide during e-beam evaporation of the refractory metal gate is annealed in vacuum at 950 C. The resulting device mobilities are between 15,000 and 20,000 cm^2/Vs at liquid helium temperature.

The first set of devices fabricated had low yields and low mobility, around 8000 cm^2/Vs, at helium temperature. Yet, even in these devices, weak structure in the transconductance was observed in both the LSSL and Q1D devices at 4.2 K. The structure appeared to be consistent with electron back diffraction from the periodic potential, and the filling of Q1D subbands, respectively. The second generation of devices resolved most of the reliability and yield problems, and allowed us to attain 20,000 cm^2/Vs mobility via vacuum annealing. These devices, however, had unfavorable line-to-space ratios in the grating, making it difficult to electrostatically control the inversion layer modulation.

In our third generation of devices we have fabricated new x-ray masks with a line-to-space ratio of approximately 1 to 2 and have made grid-gate masks in the same ratio. The grid-gate device, which has a 200 nm periodicity in both directions, should increase the strength of the conductance modulations in LSSL device. We have also transferred our device processing into the Class 10 Integrated Circuits Laboratory, and are currently fabricating new devices there on 4-inch wafers.

1.7 Study of Surface Superlattice Formation in GaAs/GaAlAs Modulation Doped Field-Effect Transistors

Sponsors

U.S. Air Force - Office of Scientific Research (Grant AFOSR-88-0304)

Project Staff

Professor Dimitri A. Antoniadis, William Chu, Khalid Ismail, Professor Marc A. Kastner, Professor Terry P. Orlando, Professor Henry I. Smith

We have used the modulation-doped field-effect transistor (MODFET) as a test vehicle for studying quantum effects such as electron back diffraction in a GaAs/GaAlAs material system. In a conventional MODFET the current transport is modulated by a continuous gate between source and drain. In our studies, we have used Schottky metal gratings and, more recently, a grid for the gate, as illustrated in figure 5a and 5b. Such gates produce a periodic potential modulation in the channel.

The grid was produced by x-ray nanolithography and liftoff. The x-ray mask was produced via holographic lithography which yields coherent gratings over areas several cm in diameter.

The MODFET is normally on; a negative gate bias of about −0.2V must be applied to pinch off conductance from source to drain. As the gate bias is raised above this point, the height of the periodic potential modulation is reduced and, simultaneously, the Fermi energy is raised (or, equivalenally, the electron wavelength is reduced) in the 2D electron gas residing at the AlGaAs/GaAs interface. When the electron wavelength phase-matches the periodic potential, electron back-diffraction should occur, provided the inelastic (coherence) length is larger than the grating period. Such back diffraction should be manifested by a drop in the conductance. Indeed, we observed such conductance modulation in a grating-gate device, reported last year.

This year, we studied grid-gate devices and, as expected, found much stronger conductance modulation, as shown in figure 6. A grid gate allows true minigaps to form in the conduction band. Due to energy broading from finite temperature and elastic scattering, the conductance modulation does not go to zero at the minigaps. The number and spacing of the structure in the conductance, and its dependence V_{DS} and temperature, are consistent with theory.

We believe the results shown in figure 6 are the first clear observation of minigaps in a grid-gate superlattice. Moreover, the period (0.2 μm) is more than an order of magnitude longer than in grown superlattices.

In another type of experiment, in which source-drain voltage was swept rather than gate voltage, we observed negative differential resistance (NDR) in the grid-gate devices, as illustrated in figure 7. The NDR effect was very sensitive to gate bias conditions. For this reason we believe it is a manifestation of sequential resonant tunneling across the periodic potential barriers in the channel. If so, this would be the first observation of resonant tunneling in a planar structure where the barrier height is modulated by an external bias.

1.8 One-Dimensional Subbands and Mobility Modulation in GaAs/AlGaAs Quantum Wires

Sponsors

Joint Services Electronics Program
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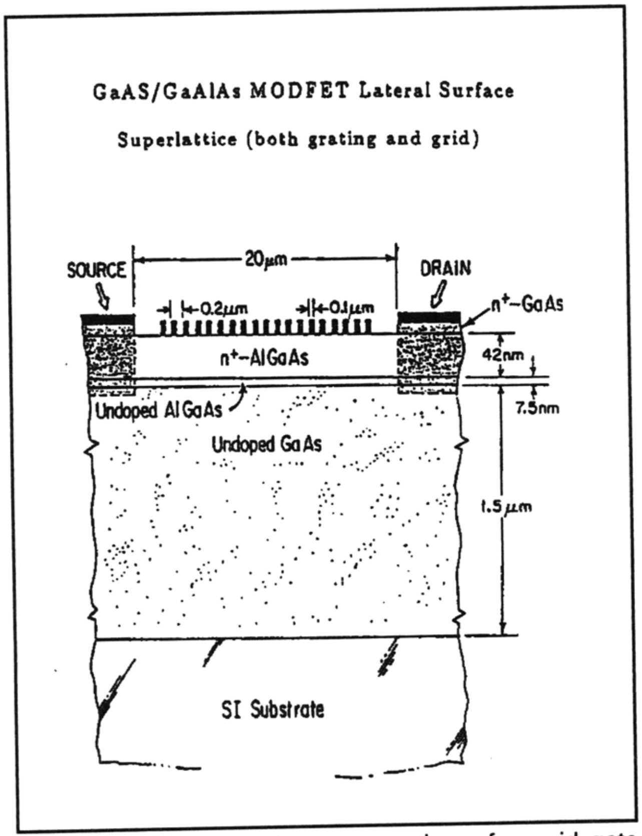

Figure 5a. Schematic cross section of a grid-gate MODFET device. The grid length in the direction of transport is 15 μm. Contacts to the grid are made by pads off to the sides of the conduction channel.

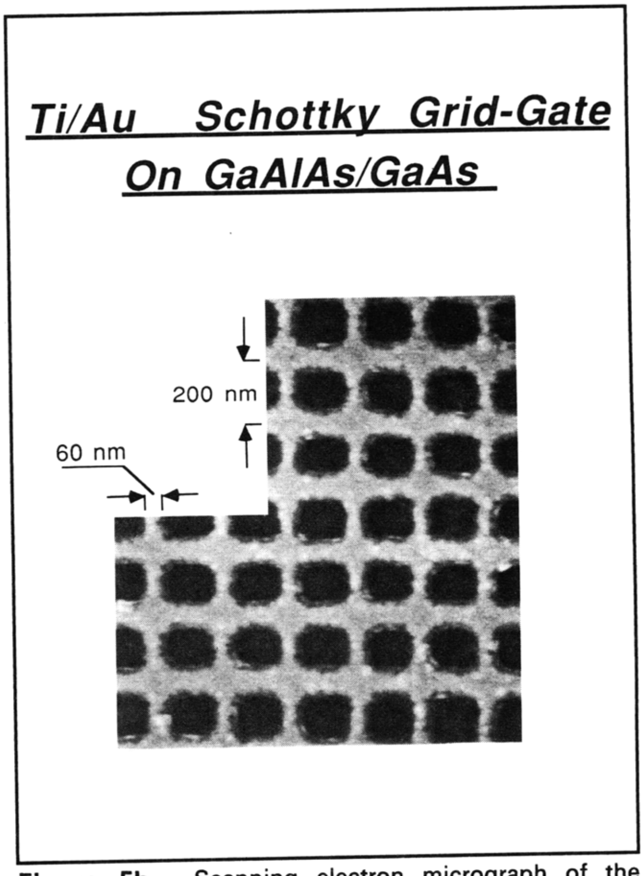

Figure 5b. Scanning electron micrograph of the 200nm-period (60 nm - linewidth) Ti/Au Schottky grid gate.

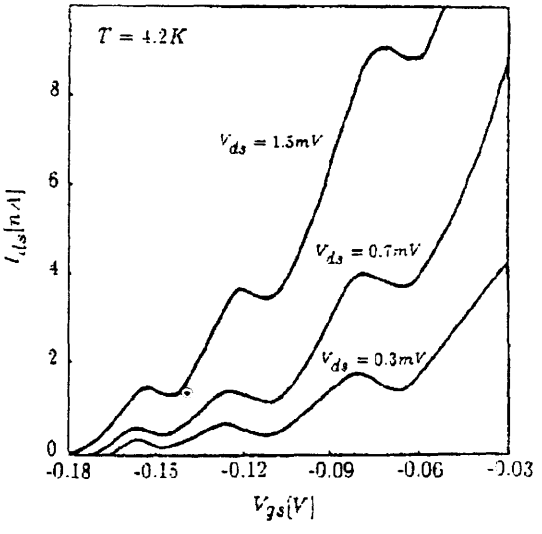

Figure 6. Source-drain current, I_{DS}, as a function of gate voltage, V_{GS}, for three different values of source-drain voltage, V_{DS}.

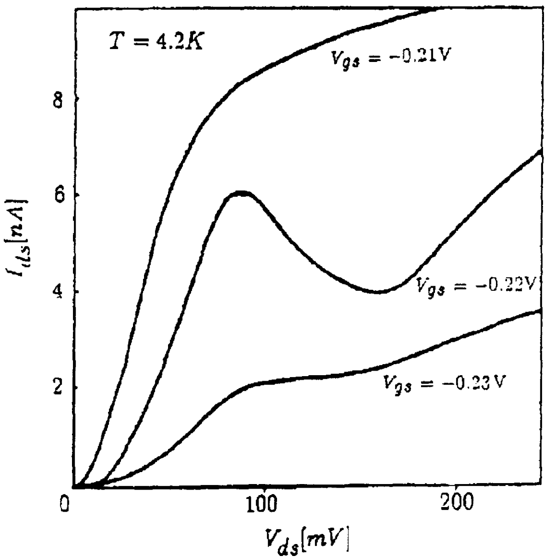

Figure 7. Plot of drain-source current, I_{DS}, versus source-drain voltage, V_{DS}, for three values of gate bias, V_{GS}. Only at V_{GS} = -0.22V is a clear negative differential resistance effect observed.

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In order to study one-dimensional conductivity in the AlGaAs/GaAs modulation-doped structure, but without the conductance fluctuations normally associated with single microscopic systems, we have fabricated arrays of 100 multiple, parallel quantum wires (MPQW), as illustrated in figure 8.

The measured Hall mobility in the 2-D electron gas at the AlGaAs/GaAs interface was 250,000 cm^2/Vs at 4.2K. The multiple quantum wires were produced by x-ray nanolithography, liftoff of Ti/Au, and ion etching. For a substrate contact, the sample was thinned down to less than 50 μm and Pt/Au evaporated on the back side. The charge concentration in the quantum wires could be increased by applying a positive bias to the back-side contact or by illumination. (There was no persistent photocurrent in these samples.) Figure 9 shows the drain-source current versus back-gate bias. The structure, which was completely reproducible after temperature cycling, is interpreted as the sequential populating of quasi-one-dimensional (Q1D) subbands. It is noteworthy that the populating of each new subband is accompanied by a clear drop in transconductance resulting from the sudden increase in available states in which to scatter.

In addition, mobility modulation was observed, manifested as an increase in the mobility in the lowest subband of the Q1D wires by a factor of 2.9 relative to the 2D electron-gas mobility, and a negative differential mobility at the onset of populating the second subband. This first observation of these effects may open up a new era of applications based on velocity modulation, rather than charge modulation, as in conventional devices.

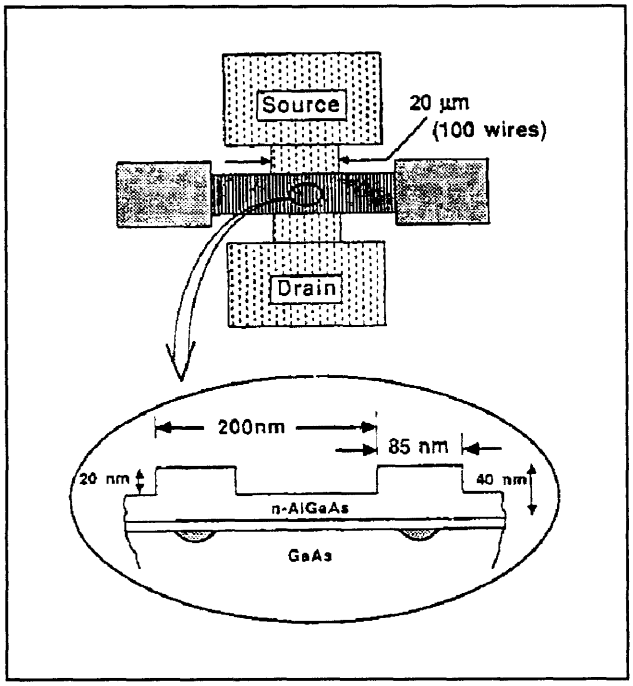

Figure 8. Schematic top view and magnified cross section of the multiple parallel quantum-wires. The Ohmic contacts to the left and right are test contacts to examine tranport perpendicular to the wires.

1.9 Study Of Electron Transport In Si MOSFETs With Deep-Submicron Channel Lengths

Sponsor

Joint Services Electronics Program
(Contracts DAAL03-86-K-0002 and DAAL03-89-C-0001)

Project Staff

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Electron conduction in sub-100-nm channel length, Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) in Si is investigated. The devices are fabricated with a combination of x-ray nanolithography and optical projection lithography. The x-ray mask, which defined the minimum lithographic features, was fabricated with conventional photolithography, anisotropic etching of a Si template, and oblique shadowing of the absorber. The gate oxide thickness for these devices was, in some cases, as thin as 2.5 nm. The primary goal was to observe non-stationary transport effects in these devices. That is, effects which arise from the rapid spatial variation of the electric field, and the resulting disparity between the actual electron temperature and the temperature that would correspond with the given field at steady-state conditions. In simple terms, transit times across the very short channels become comparable to, or shorter than, energy relaxation times.

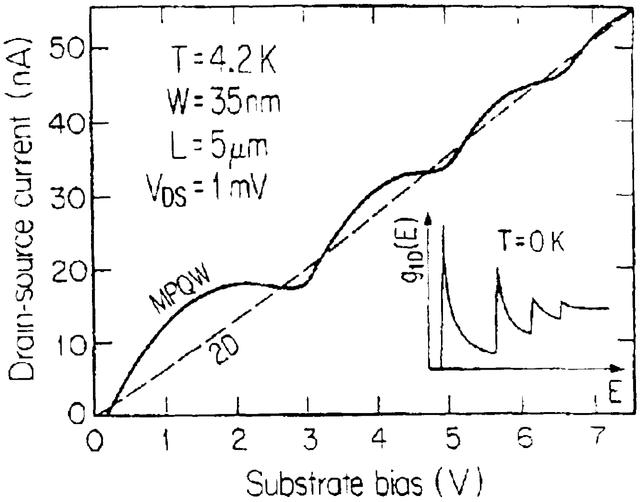

Figure 9. Drain-source current (I_{DS}) as a function of (V_{SUB}) for the multiple parallel quantum wires (solid line) and scaled down 2D channel (dashed line). The inset shows the theoretical density of states in a Q1D wire at 0 K.

To observe non-stationary transport effects, the channel mobility must be high, which demands low doping levels. At the same time, punchthrough must be prevented by heavy doping. We achieved this compromise via non-uniform doping, i.e., light doping at the Si/SiO$_2$ interface and heavy doping just below the surface. Both B and In were used as implant species. With such doping profiles we observed both velocity overshoot, and, for channel lengths below ~0.15 um, reduced hot-electron effects. Figure 10 shows the reduction of normalized substrate current versus channel length at fixed (V_{DS} - V_{DSat}) for different implant depths. We believe that this effect accompanies the onset of electron velocity overshoot over a large portion of the channel, and is due to either a decrease of carrier temperature or a relative decrease of the carrier population in the

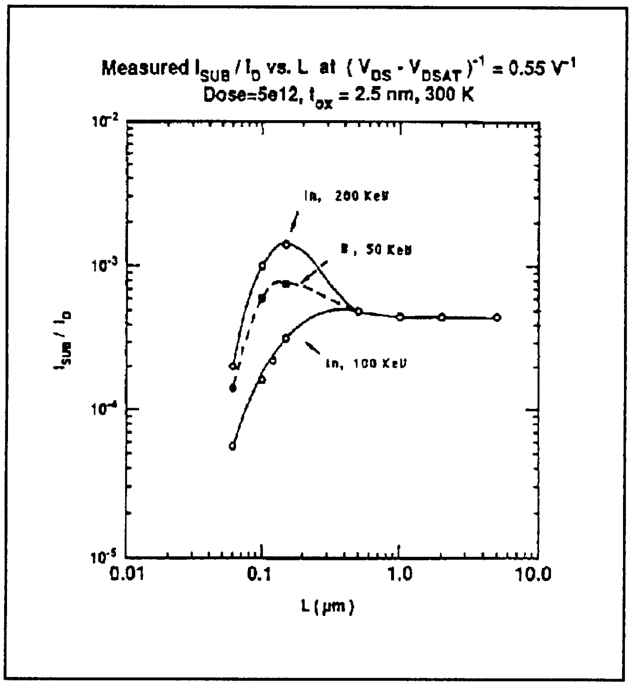

Figure 10. Plot of substrate current, I_{sub}, normalized to drain-source current, I_D, versus channel length, L, for a fixed value of (V_{DS} - V_{DSat}). Note the effect of different channel implants.

channel, or both. It is noteworthy that the shallowest implant (In at 100 keV) showed no increase at all in normalized substrate current.

A new process is under development that will yield self-aligned Si MOSFETs. The goal is to reduce the parasitic source and drain resistances, and to observe the non-stationary effects more clearly, e.g., in both substrate and gate currents. The process includes use of poly-Si gates, sidewall spacers, cobalt metallization, and silicidation. An inorganic x-ray mask technology will be used to avoid distortion and achieve precise alignment. We have also begun fabrication of p-channel, deep-submicron MOSFETs and will study non-stationary effects associated with holes. Eventually, 100-nm channel CMOS technology should be feasible.

1.10 Crystalline Films On Amorphous Substrates

Sponsor

National Science Foundation
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Project Staff

Sergio Ajuria, Jerrold A. Floro, Hui Meng Quek, Professor Henry I. Smith, Professor Carl V. Thompson III

We are investigating methods for producing oriented crystalline films on amorphous substrates. This is motivated by the belief that the integration of future electronic and electro-optical systems will be facilitated by an ability to combine, on the same substrate, a broad range of materials (Si, III-V's, piezoelectrics, light guides, etc.). Zone melting recrystallization (ZMR) of Si on amorphous SiO_2 has been highly successful, but device-quality films are obtained only at the expense of high processing temperatures since the Si must be melted. ZMR has been an important testing ground for materials combination, and for a number of novel concepts based on the use of lithography to control in-plane orientation and the location of defects (so-called defect entrainment).

The most promising approach in the long-term to crystalline films on amorphous substrates is, in our view, based on surface-energy-driven secondary grain growth (SEDSGG). In this approach, no melting or phase change occurs. Instead, we take advantage of the very large surface energies inherent in ultra-thin (~20 nm) films to drive the growth of large secondary grains having specific crystallographic planes parallel to the surface. This phenomenon has been demonstrated, as has the use of very fine gratings (~100 nm linewidths) to induce in-plane orientation (i.e., graphoepitaxy in combination with SEDSGG). Currently, research is focused on basic studies of grain growth and coarsening phenomena in ultra-thin films of model materials such as Ag, Au, Bi, and certain organic crystals.

We are also investigating means of promoting grain growth at temperatures many hundreds of degrees below the melting point.

These include ion-bombardment-enhanced grain growth (IBEGG), laser illumination, and use of selective dopants. Theoretical models for surface-energy-driven secondary grain growth were developed and have, for the most part, been confirmed by experiments on Si, Ge, and Au films. If our basic studies prove fruitful we may be able to develop a low temperature method for producing device-quality films on amorphous substrates. By means of lithography, defects in the films, such as dislocations and stacking faults, would be localized at predetermined positions, out of the way of devices.

1.11 Epitaxy via Surface-Energy-Driven Grain Growth

Sponsor

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Project Staff

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Grain growth in polycrystalline films on single-crystal substrates can lead to formation of low-defect-density or single-crystal films. This process is expected to minimize the production of extended defects in large misfit systems, a problem difficult to avoid in conventional heteroepitaxy. We are investigating surface-energy-driven secondary grain growth in semiconductor (e.g., GaAs) and metal (e.g., Au and Ag) films on single crystal substrates. We are also further developing the theory of epitaxy by surface-energy-driven secondary grain growth, including effects due to grain boundary motion and coarsening via surface diffusion.

1.12 Submicrometer-Period Gold Transmission Gratings for X-Ray Spectroscopy and Atom-Beam Interferometry

Sponsor

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X-Opt., Incorporated

Project Staff

Erik H. Anderson, Dr. Mark L. Schattenburg, Professor Henry I. Smith

Gold transmission gratings with periods of 0.2 μm, and thicknesses ranging from 0.1 to 1 μm are fabricated using x-ray lithography and electroplating. The x-ray masks are made with holographic lithography. Transmission gratings are either supported on thin (1μm) membranes or are made self-supporting by the addition of crossing struts. They are supplied to external laboratories for spectroscopy of the x-ray emission from a variety of sources.

Self-supporting transmission gratings in both gold and thin-film chromium were provided to Professor David Pritchard's group for use in experiments to demonstrate the diffraction of neutral sodium atoms by gratings. The sodium atoms had a de Broglie wavelength of 17 pm (0.17 Å). This was the first clear demonstration of atomic diffraction by an array of slits. The gratings can divide and recombine an atomic beam coherently, and may provide the easiest route to the realization of an atom wave interferometer.

1.13 High-Dispersion, High-Efficiency Transmission Gratings for Astrophysical X-Ray Spectroscopy

Sponsor

National Aeronautics and Space
Administration
(Grant NGL22-009-683)

Project Staff

Erik H. Anderson, Professor Claude R. Canizares, Dr. Mark L. Schattenburg, Professor Henry I. Smith

Gold gratings with spatial periods of 0.1 to 1.0 μm make excellent dispersers for high resolution x-ray spectroscopy of astrophysical sources in the 100 eV to 10 KeV band. These gratings are planned for use in the Advanced X-Ray Astrophysics Facility (AXAF) which will be launched in the mid 1990's. In the region above 3 KeV, the requirements of high dispersion and high efficiency dictate the use of the finest period gratings with aspect ratios approaching 10 to 1. To achieve this we first expose a grating pattern in 1.0 μm-thick PMMA over a gold plating base using x-ray nanolithography. Gratings have a period of 0.2 μm (linewidth 0.1 μm). Gold is then electroplated into the spaces of the PMMA to a thickness up to 1 μm. Flight prototype gratings have been fabricated and are undergoing space-worthiness tests. In the initial stage of this program we used the carbon K x-ray (λ= 4.5 nm) which required that the mask and substrate be in contact to avoid diffraction. This, in turn, caused distortion of the grating. To avoid this problem we are developing a new technology of microgap x-ray nanolithography using the copper L x-ray (λ= 1.33 nm).

1.14 Soft X-Ray Interferometer Gratings

Sponsor

KMS Fusion, Incorporated

Project Staff

Erik H. Anderson, Dr. Mark L. Schattenburg, Professor Henry I. Smith

In the soft x-ray region of the electromagnetic spectrum (1 to 10 nm), reliable optical constant data is scarce or non-existent. In order to fill this gap, an achromatic interferometer instrument is under construction at KMS Fusion Inc. The critical optical components of this instrument are a set of matched, 200 nm-period, gold transmission gratings which will be fabricated at MIT. Because these gratings will be used in an interferometer, the phase-front quality must be extremely good and, at the same time, the lines must be free-standing, i.e. have no continuous support structure that would attenuate the x-rays.

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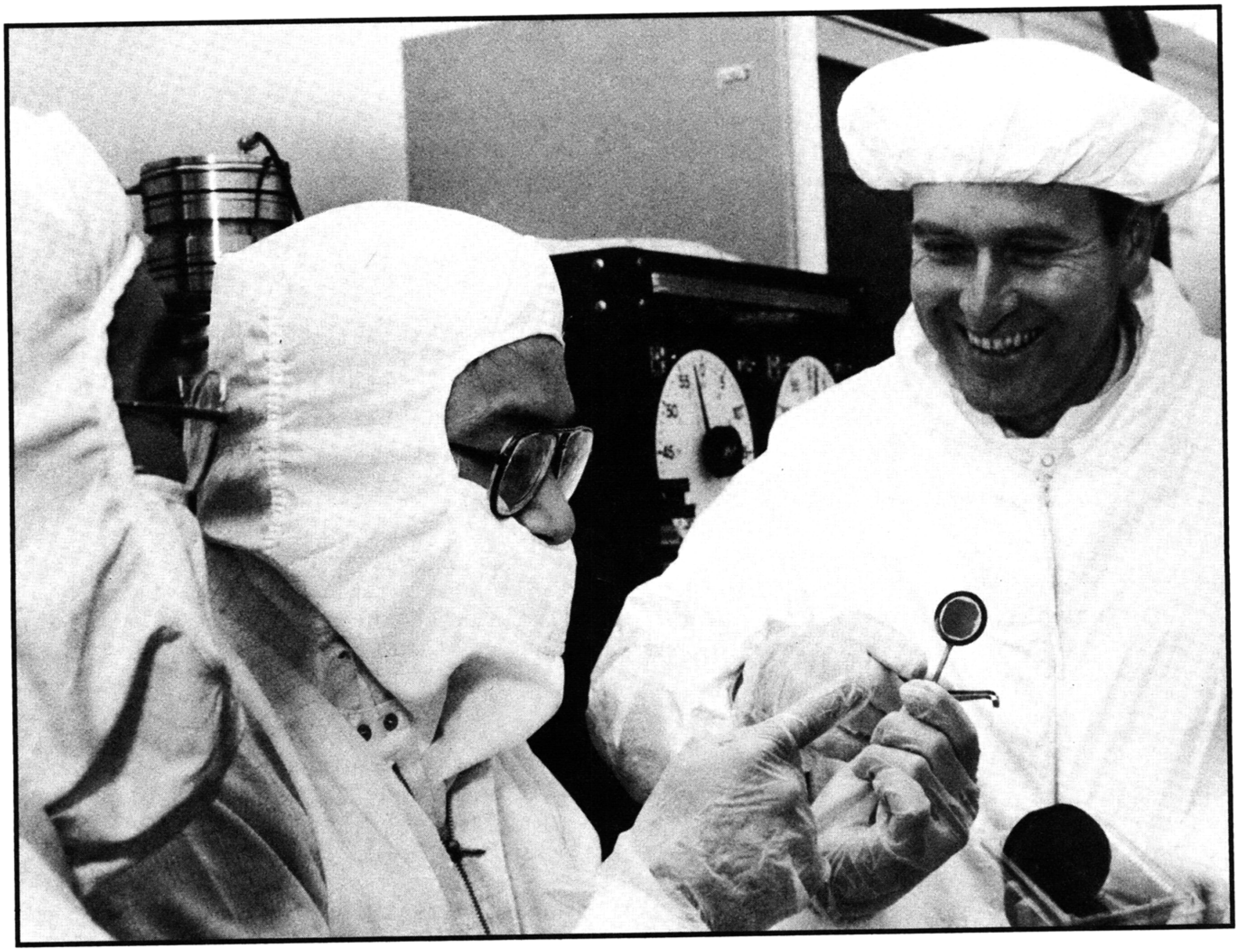

From left, graduate students William Chu and Anthony T. Yen, and Professor Henry I. Smith