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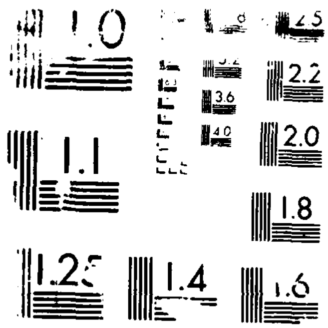
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Focused Ion Beam Fabrication of Graded Channel FET's in GaAs and Si

Semiannual Technical Report

1 January 1987 to 30 June 1987

by John Melngailis

DARPA ~~DAPRA~~/DOD Contract

MDA 903-85-C-0215

Massachusetts Institute of Technology
Research Laboratory of Electronics
Cambridge, MA 02139

"Focused Ion Beam Fabrication of Graded Channel Field Effect Transistors in GaAs and Si"

Introduction:

The focused ion beam is a unique semiconductor fabrication tool with many applications. Of these, markless/resistless implantation is perhaps the one with the greatest potential impact. It permits implant dose to be varied from point to point on a wafer. Thus devices can be fabricated side by side with different doping densities, and the doping density can be varied from point to point within a device. Thus lateral gradients of doping are possible. The aim of this contract is to produce field effect transistors in GaAs and Si with graded implants from source to drain. To achieve this, alignment procedures have to be developed to permit the focused ion beam implant to be positioned precisely relative to features fabricated by conventional means. In addition, models of the behavior of graded devices have to be developed.

Personnel working on the program:

Jarvis B. Jacobs, Grad. student, Elect. Eng. & Comp. Science
Henri Lezec, Grad. student, Elect. Eng. & Comp. Science
Christian Musil, Grad. student, Physics
Len Mahoney, Lincoln Laboratory
Dimitri Antoniadis, Associate Professor of E.E. & C.S., Coprincipal Investigator
John Melngailis, Principal Research Scientist, R.L.E., Principal Investigator

Progress During the Fourth Half Year Period:

During this half year period our efforts have concentrated on preparing silicon devices for fabrication, preparing and implanting GaAs samples, and installing the focused ion beam machine at MIT.

1. Machine and Technology Development

(The purchase and development of the focused ion beam machine, called the Microfocus, is supported by MIT funds through the Microsystems Technology Laboratories. The outcome, however, has a direct effect on the present project and is therefore mentioned here. Also, when the machine is used for the first time to perform a demanding research task, this in itself develops the machine capability.)

The Microfocus machine was disassembled and moved to MIT on March 13, 1987. Before moving it had opertaed reliably at the manufacturers plant in four months. 0.1μm dots were exposed in PMMA. Complicated patterns such as Fresnel zone plates were written. The system has now been installed at MIT and is operating. Full voltage, 150 kV, has been applied, and the system has operted reliably at 120 kV with both Au/Si sources and Ga sources. The resolution was tested by putting a 0.2 m period grating (0.1 μm linewidth) into the machine. Since the lines in the grating could clearly be resolved (see Fig. 1), the

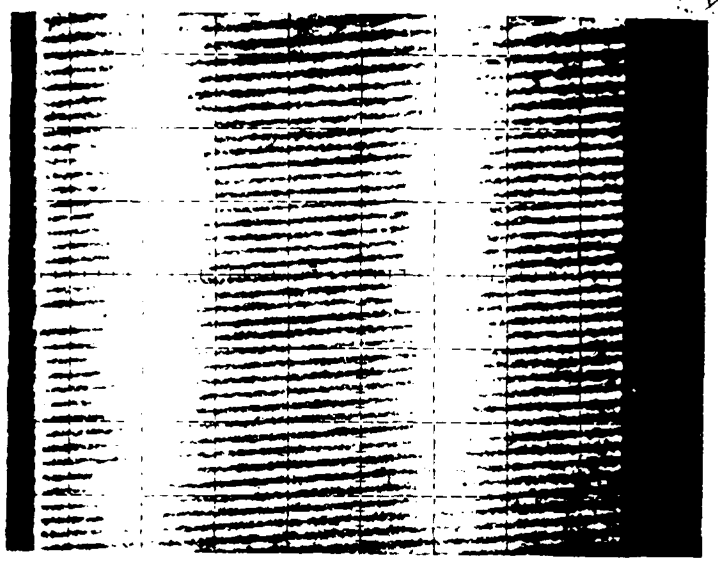

Fig. 1 Scanning ion micrograph of a free standing gold grating taken with 118 kV Ga ions. Period of the gratir, is 0.2 μm, linewidth 0.1 μm. The grating is free standing. The blurred area is due to the support structure under the grating.

diameter of the beam is near 0.1μm. Experiments were carried out to test the alignment of the upper part of the column. Although the performance of the column at this point is adequate for our experiments, it is not as good as that of the two sister machines at Hughes Research Laboratories. However, because realignment is time consuming, we have postponed it until we have achieved some results with the machine in its present state. Various tests of PMMA exposure and ion milling were also carried out.

2. Si Device Fabrication

A mask set has been designed and built which has transistors of various gate lengths between 2 μm and 9 μm. See Fig. 2. A set of six wafers had the fabrication steps performed on it up to the channel doping. They are ready for the focused ion beam implantation. At the moment we do not have available the ion species needed for implantation into Si namely As and B. We expect to receive the needed ion sources from Hughes Research Laboratories.

3. GaAs Devices:

The devices fabricated earlier with graded doping, which clearly showed asymmetrical DC characteristics, have been tested at high frequency. Some of the devices showed gain up to 18 GHZ but so did a control device with uniform doping profile. One of the graded devices was tested backwards, i.e., with the drain grounded instead of the source. Its f_{max} dropped from 18 to 13.5 GHZ. This is encouraging since it indicates that the gradient in the doping apparently can influence the maximum frequency of operation.

A process has been conceived for implanting the channel of the FET with focused ion beam in a self aligned manner. It consists of putting a sandwich of Si_3N_4, PMMA, SiO_2 and PMMA over semiinsulating GaAs, see Fig. 3. The channel is doped lightly by focused-ion-beam implanting through the sandwich. A gradient can also be produced. The PMMA is not completely exposed here. The regions adjacent to the channel are also doped but more heavily. They are exposed so that development removes the PMMA layer, leaving only the portion over the gate. The SiO_2 is then etched, and the underlying PMMA is removed everywhere except under the gate electrode. SiO_2 is deposited and the remaining PMMA removed. The metal electrode is evaporated into the opening which is automatically aligned with the doped channel.

We have also purchased some GaAs wafers with the surface cut at 8^0 off the crystallographic plane. This will prevent channeling during implantation. Test structures were prepared on the wafers and implanted. The implants consisted of heavily doped contact pads with more lightly doped structures in between, such as, gradients in the doping, or gratings. We will measure Gunn oscillations and observe the effect of these structures on the output. For example, a gradient may be used to produce a variable frequency as the voltage is varied, and a grating may produce higher harmonics.

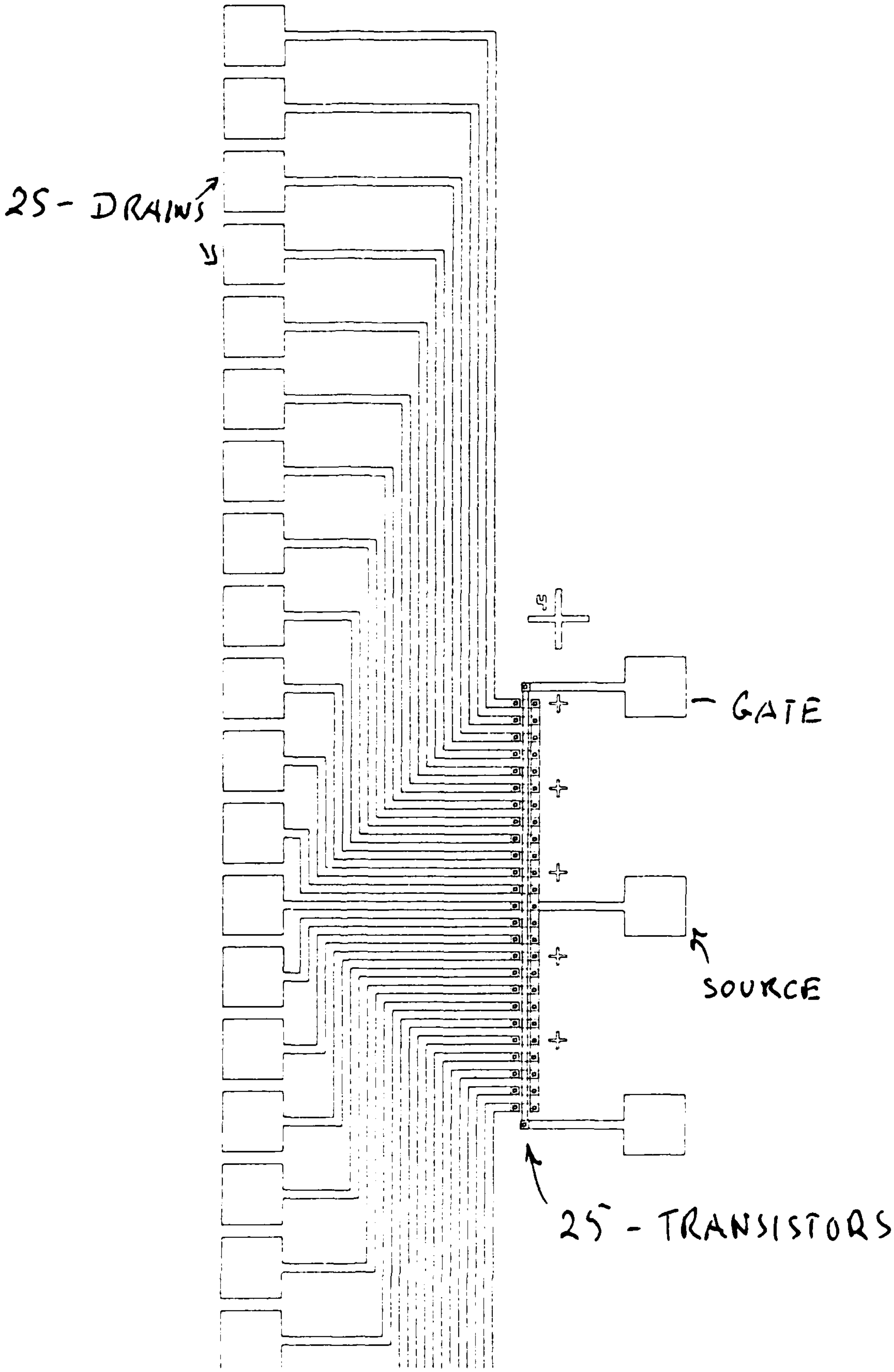

Fig. 2 A diagram of the structure fabricated on silicon. It consists of a row of 25 transistors with common gate and source connections. Each transistor can be implanted differently by the focused ion beam.

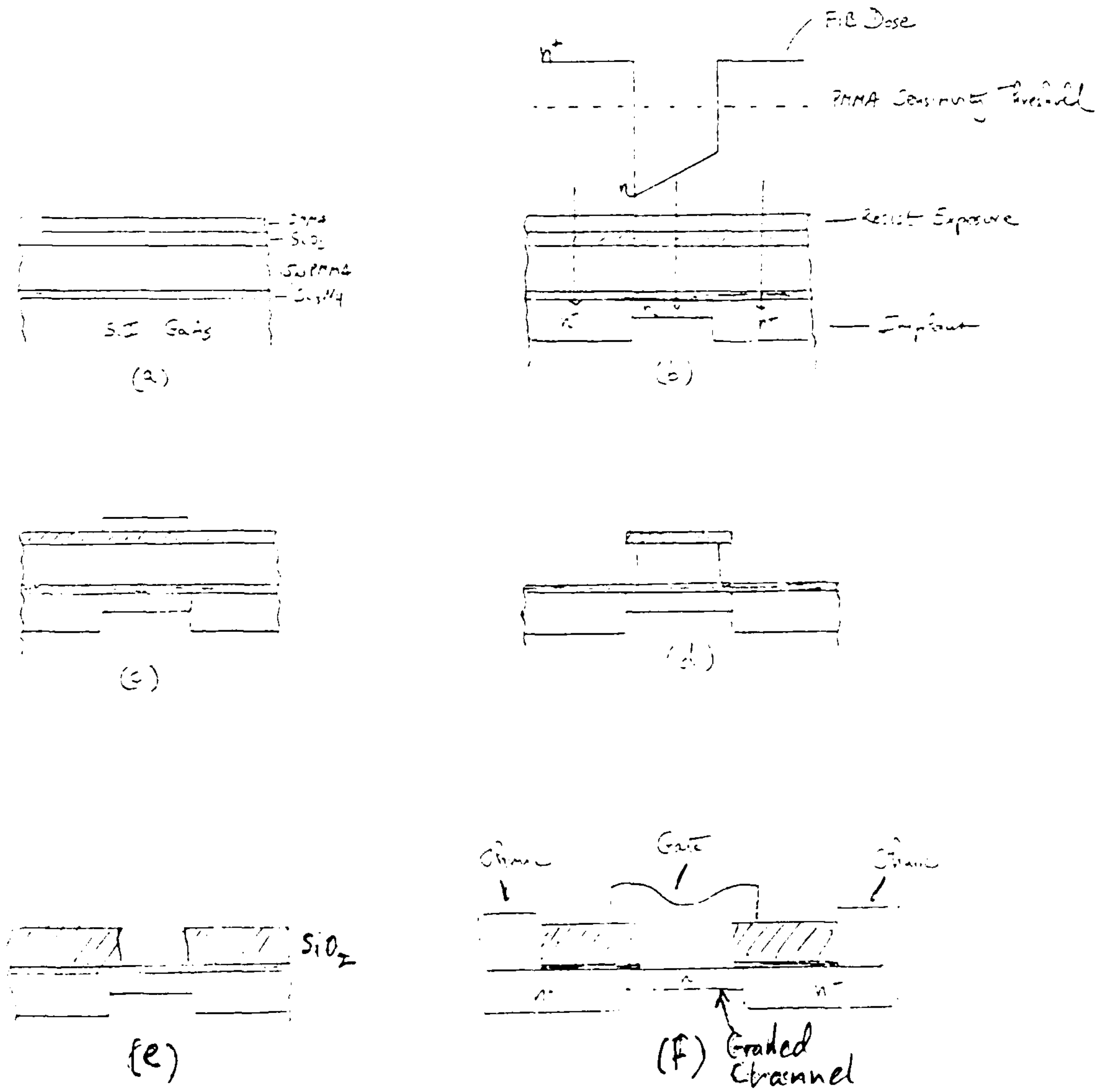

Fig. 3 Process sequence for producing a self aligned GaAs FET with a gradient of doping in the channel.

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