FOCUSED ION BEAM FABRICATION OF GRADED CHANNEL FET'S (FIELD EFFECT TRANSISTORS) MASSACHUSETTS INST OF TECH CAMBRIDGE RESEARCH LAB OF ELECTRONICS J MELNGAILIS UNCLASSIFIED 27 OCT 86 MDA903-85-C-0215
Focused Ion Beam Fabrication
of Graded Channel FET's

in GaAs and Si

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Work by J. J. Melngailis and his collaborators is summarized here.
"Focused Ion Beam Fabrication of Graded Channel Field Effect Transistors in GaAs and Si"

Background:

The main goals of this research program are to use the focused ion beam system for fabricating field effect transistors in GaAs and in Si with graded doping profiles, and to model the behavior of these novel device structures. The devices are fabricated by conventional processing steps except that the channel doping is performed with the focused ion beam. This permits the channel doping to be varied as a function of distance along the surface from source to drain. To achieve this goal, sophisticated performance is required from the focused ion beam system: the deflection has to be calibrated; alignment marks have to be located; rotation of the sample has to be corrected for; and a desired doping profile has to be implanted. The fabricated device must be tested, and models of the behavior 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 A. Antoniadis, Associate Professor of E.E.& C.S., Coprincipal Investigator
John Meingailis, Principal Research Scientist, R.L.E., Principal Investigator

Progress during the Second Half-Year Period

During this second half-year period of the research program our work has concentrated on achieving focused ion beam implants in GaAs and in Si, and
on further developing the models of the devices which are being built.

1. GaAs FET's:

The focused ion beam system was calibrated and operating procedures were developed to perform the graded implants at the desired locations. The system has a precision x-y stage whose position is monitored with a laser interferometer with an accuracy of 0.01 μm. This was the "ruler" used to calibrate the electrostatic beam deflection. This calibration was done by moving the stage a precise distance and then applying beam deflection to bring a given feature back to the center of the screen. In addition, rotation was corrected, and alignment to existing features was developed. The system was operated with a Au/Si source, which emits both Si+ and Si++ ions. Beam profiles were measured by implanting Si++ ions in PMMA and varying the doses over 5 orders of magnitude.

With the operating procedure developed and properly tested implants into GaAs FET's were carried out. Both Si+ and Si++ ions were used at accelerating voltage near 100 kV. (The system had been tested to 150 keV.) Control structures were implanted by a conventional implanter, and then identical structures were implanted with the focused ion beam. In addition, thirty FET's were implanted with a gradient of doping from source to drain. Eight different gradients were used to give a doping profile of \( n(x) = n_0(1 + ax) \) where \( n_0 = 4.6 \times 10^{12} \text{ ions/cm}^2 \), \( x \) is the distance in μm, and \( a \) takes on eight values from 0.05 to 0.4 μm\(^{-1}\). Special alignment marks were ion milled into the GaAs surface to line up the gate structures with the focused ion beam implants. To achieve all of this, the focused ion beam system
was operated for four contiguous days. Considering the complexity of
the system and past difficulties, we were encouraged by this
performance. The standard fabrication steps are being carried out to
complete the device fabrication and to test the devices.

2. **Implantation into Si:**

A set of test wafers including both n type and p type has been
fabricated, which has structures for measuring both implant profiles as
a function of depth and Hall coefficients. The purpose of these
structures is to verify focused ion beam self annealing results
reported by researchers at Hitachi, to measure the depth profile of
focused ion beam implants compared to conventional implants, and to
eexercise the system. The conventional, control implants have been
carried out, and one wafer has been focused-ion-beam implanted with As⁺
at 80 kV with a Pd/B/As source.

A mask set with 4 groups of 22 transistors each has been designed.
Fabrications issues, such as alignment marks from level to level and
alignment marks for focused ion beam implants, have had to be resolved.
The mask set is now ready to be fabricated. The channel doping step of
these transistors will be carried out by the focused ion beam while the
other steps will be fabricated conventionally.

3. **Modelling:**

A computer simulation of the graded channel GaAs-FET’s has been
carried out. An existing simulation program, PISCES, has been adapted
for use in GaAs. A finite element analysis predicts that with a 15%
increase in doping from source to drain, a 45% increase in the
transconductance is expected while the pinchoff voltage remains constant. Calculations with a simple analytic model have also been carried out and predict improved performance as a result of grading the channel doping. In silicon the existing device models have been improved to include the effect of the dependence of mobility on depth and on the electric field generated by the gate. This is needed to correctly understand the effect of graded doping profiles on the channels of MOS devices. The functional form of the microscopic mobility model has been determined and experimentally measured mobility values have been reproduced. This model will be included in our device simulators MINIMOS and PISCES.
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