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Fine Focused Ion Beams*

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The use of a focused ion beam for direct implantation of dopants into a semiconductor substrate results in appreciable simplification in the processing of semiconductor devices. We have demonstrated that liquid metal (LM) field-ionization sources (based upon the electrostatic formation of an emitting cusp of liquid metal) offer the necessary high brightness to make focused ion beam microfabrication feasible. This paper reports upon three developments: (1) the development of eutectic-alloy LM ion sources for the production of boron and arsenic for direct implantation of silicon devices, (2) the fabrication of a FET using a Au-Si beam that was mass separated at the target, and (3) the development of a three-lens variable-energy focusing column that incorporates a mass-separator of low aberration.

The mass spectra of ion emission from the boron and arsenic sources show that the stoichiometric fraction of boron and arsenic is emitted. We have also demonstrated that the high vapor pressure of arsenic can be suppressed in the eutectic liquid metal, and that boron is predominantly emitted as a singly ionized species while arsenic is emitted as both singly and doubly ionized species. The mass spectra of these sources will be presented.

Using a Au-Si liquid-metal-ion source[1], the active channel and ohmic contact regions for depletion-mode Schottky-barrier GaAs FETs have been doped. The beam was formed in a single-accelerating lens column[2]. The Au and Si ions were separated at the target by means of a stopping layer technique. This technique has been shown to yield excellent Hall mobilities for B doped Si and Be doped GaAs[3]. We have shown that the damage produced in Si substrates using a high current density beam (~1 A/cm^2) for implantation is only about a factor of two larger than that produced by conventional implantation at current densities of 0.5 $\mu A/cm^2$.[4]

Implantation doping of the FET was performed through a stopping layer structure consisting of 800 Å of Al over 400 Å of Si_3N_4. After doping with the focused ion beam, the Au-doped Al layer was removed and the underlying Si_3N_4 layer was overcoated with SiO_2. It is estimated that less than .01% of the Au in the beam entered the GaAs during implantation. The wafer was annealed at 850°C for 30 min. The dielectric encapsulants were then stripped. Conventional lithography was used to define Au: Ge/Ni/Au metal contacts and 1.5-μm-long by 65-μm-wide Au gates.

I-V curves have been obtained for several of the FETs. Saturation currents of several milliamperes and transconductance values at saturation of 1 mS were measured. Devices doped at impurity levels greater than 10^{17} cm^{-3} showed typical Gunn-effect oscillations. Several implant doses were used, and four FETs were doped at each dose. All identically implanted FETs demonstrated similar performance.

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Finally, a new focusing column has been constructed that incorporates the new ion sources. It has the capability for focusing to sub-micrometer dimensions with mass-separation, a variable beam voltage of up to 150 kV, and a spot current of near 1 A/cm^2. A high-speed electrostatic-deflection system with microprocessor control allows this machine to perform simple pattern exposures. Examples of the operation of this microfabrication system with eutectic alloy sources will be presented.

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