2-5 *INVITED*: Ion Implantation into MOS Structures

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Ion implantation has already been recognized as an established processing technology in the field of silicon devices, especially for low dose applications like MOS and Junction FET's, variable capacitance tuning diodes and possibly base region of bipolar transistors.

Concerning MOS devices, on the other hand, detailed studies about their stabilities were already completed and research efforts are now concentrated upon obtaining novel device characteristics and higher degree of integration by making use of new device structures and materials and, of course, improvement of processing technologies. One of the features of the implantation technology is to realize highly controlled precise doping of the impurities at the lower dose level, which was already adopted in obtaining improved MOS characteristics.

Although MOS structures consist of five regions (M, O, S and M-O, O-S interfaces) most of the implantation studies were concentrated so far upon the impurity doping into surface region of the substrate silicon. The effect of implantation upon MOS structures may thought to be much extended when one considers to what part of other four regions ions are implanted or what kind of ion effect and ion species are utilized other than the conventional doping effect of donor and acceptor implantation. Ion species like sodium or phosphorus that show specific effect upon MOS structures or ion species like aluminium, oxygen and silicon which may affect equilibrium stoichiometric relations at M-O and O-S interface may be some of these examples.

Apart from applications, generation of $Si-SiO_2$ interface states by implantation into O-S interface and observation of behavior of generated defects by electrically measureing these interface states, implantation offers such new observation techniques which by no other means been hitherto possible.

In Table 1, concievable effects of implantation into each regions of the MOS structures are summarized. Following items in which our experimental data were obtained will be discussed.

<u>Implantation into Silicon Substrate</u>

Many applications of the implantation into substrates are already established ; we have reported self-aligned FET process with silicon gate and shift of threshold voltage by channel doping. The discussions about a value of threshold voltage when active impurities were implanted as Gaussian distribution and its change by implantation parameters as well as carrier mobility and low frequency noise behavior of the implanted MOSFET's were also reported by us.

Reverse breakdown voltage of MOSFET's can be improved by implantation of impurities at the surface region between gate and drain to reduce surface electric field. Higher breakdown voltage devices can be compatible with conventional devices in a single chip of MOSIC structure without any complexity in processing.

Implantation into Oxide-Silicon Interface

In the case of threshold voltage shift by channel doping scheme, implantation through oxide film usually generates Si-SiO_2 interface states. By low temperature and short time annealing, these states can be diminished rather easily, however, investigations about the nature of interface states and implantation generated defects gives some extrapolative informations for the origin of process sensitive as-grown Si-SiO_2 interface states. We have found that density of induced charged interface states was proportional to the number of displaced atoms independent of the ion species implanted. Discrete energy level arround 0.4 eV from the conduction band edge was found in as-implanted samples, and annealing of these states occured 200 - 300 °C range, with the activation energy of 0.3-0.4 eV.

Implantation into Oxide

Non-volatile memory effect devices were developed by using MNOS or MAOS multilayered dielectric films to store electronic charge in the traps in and/or at the interface of the dielectric films. The intentional control of the nature and density of such traps have not been attempted yet, however, we have carried out implantation of silver ions into oxide film on silicon substrate to form such charge trapping centers. Some of the results of our observed memory effect phenomena will be presented.

Table 1

Various effects of ion implantation into MOS structures.

Region implanted	Effects and applications
Metal	new metallization
Metal-oxide interface	change of interface properties contamination trap
Oxide	V_{FB} shift memory effect stable oxide radiation hardening diffusion source etching mask
Oxide-silicon interface	change of interface properties interface state study
Silicon substrate	threshold voltage shift, field isolation E/D in one chip high voltage device self-aligned gate, ROM information writing well doping for CMOSIC's