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# Properties of MOS Structures Prepared on Substrates having Ion Implanted Impurity Distribution Profile

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Intentional shift of gate threshold voltage of MOSFET's was already reported by several workers[1),2)] as a result of successful application of ion implantation technology. However, to predict various characteristics of the ion implanted MOS-FET's, it is necessary to analyse theoretically the surface potential of the MOS structures having a substrate with non-uniform impurity distribution profile. Brotherton[3)] reported the analysis in the case of exponential impurity distribution and Tanaka[4)] gave complementary error function case to a considerable extent assuming that impurities are introduced from the surface by diffusion. There is little information, however, in the case of implanted gaussian impurity distribution as it requires additional parameter to describe the impurity distribution. The purpose of this work is to discuss the calculation of surface potential of the MOS structures prepared on a substrate having ion implanted gaussian impurity profile and to compare results with the experimental results obtained under various implantation conditions.

The potential profile of the MOS structure is given by the following Poisson's equation,

$$\frac{d^2U}{dX^2} = \sinh(U-u_B) \pm f(X)/2n_i + \sinh(u_B) \qquad (1)$$

where U is defined as $u_B-u$, and u is the Fermi potential measured from the intrinsic Fermi level in kT/q unit, and $u_B$ is u for the bulk. X is the distance from the surface in the Debye length unit, and f(X) is the profile of implanted impurity. Equation (1) can be solved by obtaining a pair of initial conditions which satisfy the boundary condition of $U_{X\to\infty}=0$.

Examples of results are shown in Fig.1(a) and 1(b) for acceptor and donor implantation both into p-type substrate with impurity concentration of $10^{15}$ $cm^{-3}$. As U indicates the deviation from the bulk Fermi potential, these curves show directly the shape of the band edge as a function of surface electric field. Fig. 1 shows that the introduction of acceptors increases the inversion capacity and requires higher field to generate the same amount of carriers as compared with uniform substrate case, while donor implantation reduces the inversion capacity and requires negative field to deplete surface carriers. And in the latter case, a potential valley appears in the weak inversion condition, which implies that carriers are populated far from the $Si-SiO_2$ interface(300-800 Å in this case). In the MOS structures the carriers will be less affected by the $Si-SiO_2$ interface conditions. We have some experimental indications in the measurement of surface carrier mobility and of low frequency 1/f noise, of induction of carriers away from the interface.

The shift of gate threshold voltage of ion implanted MOSFET's is related to the change in surface field required to generate the same amount of surface carriers as in the strong inversion condition of an un-implanted MOSFET. Surface carrier density is readily obtained from the potential curve, and an example for typical implantation condition is shown in Fig. 2. Increase in implantation dose results in the parallel shift of the curve, and in the implantation conditions involved, the amount of the voltage shift will be proportional to the total impurities added by implantation as shown in Fig. 3. The experimental data are also plotted in Fig. 3, and show a good agreement with theoretical prediction.

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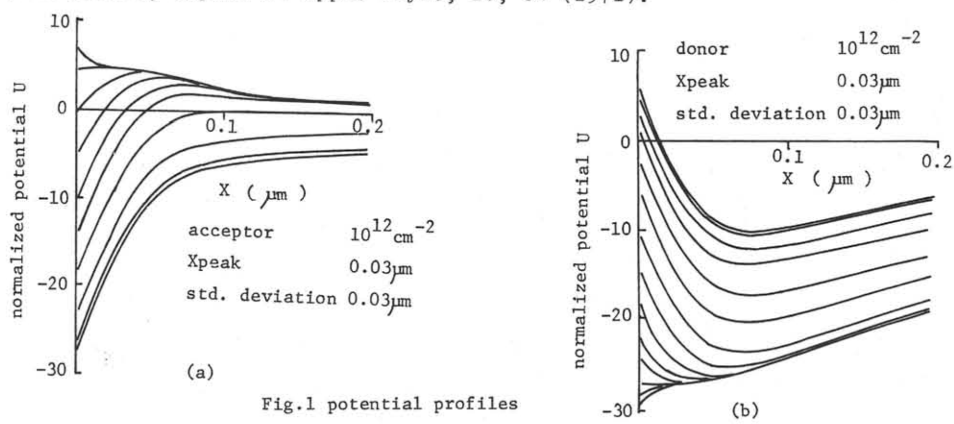


Fig.1 potential profiles

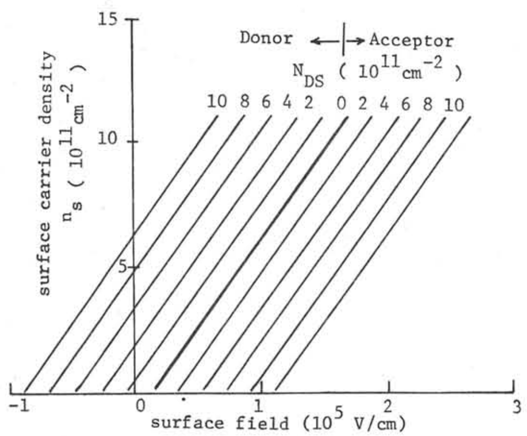


Fig. 2 computed curves

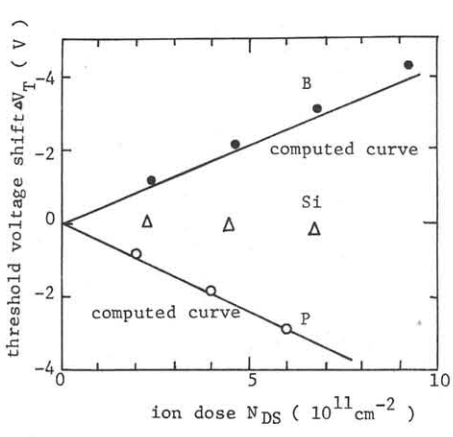


Fig.3 experimental results