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New Charge Control Technology by Stencil Mask Ion Implantation

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1. Introduction

Ion implantation is one of the key processes in the manufacturing and engineering of semiconductor devices. Ion implantation, however, induces charge buildup of wafer and causes destruction of semiconductor devices. So, conventional ion implanter has either electron flood gun or plasma flood gun to neutralize the ion beam and wafer. However, the charge neutralization strongly depends on implantation condition.

We already proposed Stencil Mask Ion Implantation Technology (SMIT) and showed that the several merits for manufacturing, notably shorter process time, lower cost, and smaller clean-room space [1]. Recently, we found new charge neutralization effect in SMIT. In this paper we will discuss the charge neutralization effect by SMIT and propose new charge control technology.

2. Experimental

2.1 Equipment

Since the experimental equipment has been presented in detail elsewhere [1], we show an overview of the SMIT system. The system consists of ion source, analyzing magnet, ion scanner, ion deflector/collimator magnet, $XYZ\theta\phi$-stage, and alignment optics. As shown in Fig. 1., The ion beam coming from the ion source is bent by the deflector/collimator magnet, passes through holes of a stencil mask set on a wafer, and is implanted into the selected region of the wafer. The mask bias and the distance between the wafer and the mask can be controlled.

2.2 Experimental Procedure

Phosphorus ions with 50-150 keV were implanted into 300-nm SiO_2 films on (100)Si wafer to a dose of $2\times10^{13}cm^{-2}$. The distance between the wafer and the mask varied from 100 to 1000 μm. Mask bias varied from -4V to +10V. In this experiment a stencil mask (membrane thickness:10μm) that had 15x15mm-pattern area with 2x2μm square array (pitch: 4μm) was used. In order to compare with the case of implantation without mask, implantation was performed 4 times and the relative mask position was displaced by 2μm in x or y direction. After ion implantation, surface potential of the Si wafer was measured by multi probe system and charge densities at the implanted areas were evaluated.

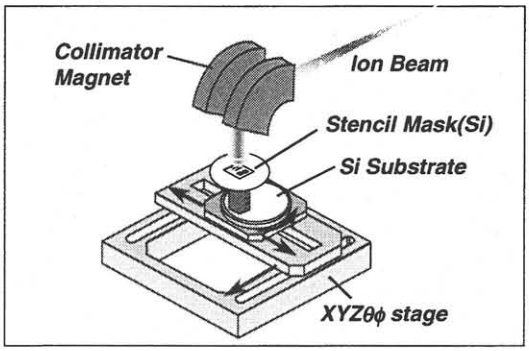

Fig.1. End station chamber of the SMIT system. Here, alignment optics is omitted.

3. Results and Discussion

Figure 2 shows a measured potential map. Charge density was calculated from the surface potential. Here the potential resolution is 0.1V and corresponds to charge density of $2\times10^{10}cm^{-2}$. We use the value at the center of the implanted area as an experimental value.

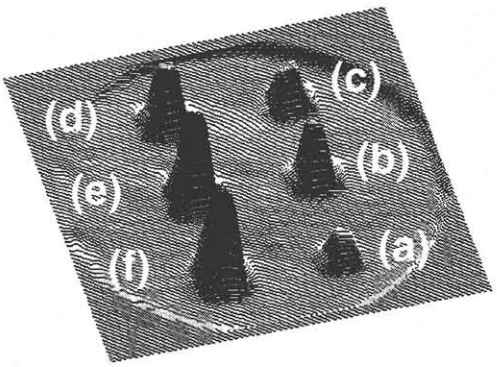

Fig.2. Surface potential of implanted wafer. Mask bias is set at 0V and distances between mask and wafer are (a)150, (b)200, (c)250, (d)300, (e)350, and (f)400μm, respectively.

3.1 Acceleration Energy Dependence

Figure 3 shows the dependence of the charge buildup on acceleration energy of implanted ions. Without stencil mask, the charge gradually decreases as acceleration energy increases. There are two possible reasons. One is that secondary electrons ejected from wafer surface neutralize the wafer and the number of the electrons depends on energy. The other is that a depth profile affects the charge depletion. We cannot separate these two contributions, however, a large

amount charge remains on the wafer without stencil mask in the case of implantation with low acceleration energy.

We can also see the effect of the stencil mask in Fig.3. Used with stencil mask, the charge buildup is quenched and is independent on acceleration energy. Because sufficient charge remains on the wafer without stencil mask, we used acceleration energy with 50 keV as condition of other experiment.

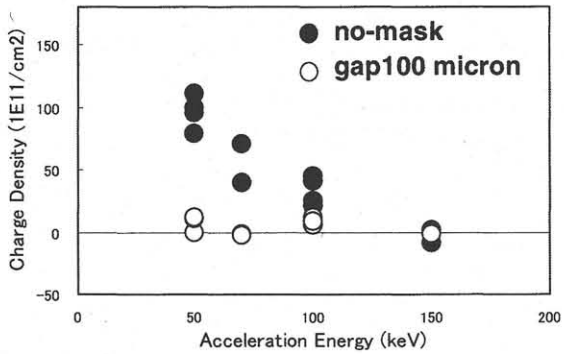

Fig. .3. Charge density vs. acceleration energy. Phosphorous ion was implanted to a dose of $2x10^{13}cm^{-2}$ into 300-nim SiO_2 film. Without stencil mask (closed circles), charge density has an acceleration energy dependence. On the other hand, with stencil mask (open circles), charge on the wafer decreases to zero.

3.2 Mask Bias Dependence

Mask bias dependence of charge density is shown in Fig.4. Charge density is well defined as linear function of a mask bias. Two possibilities are considered. One is that the secondary electrons return to wafer. It is reasonable to expect that secondary electrons ejected from the wafer surface affect the charge neutralization. The secondary electron feels a potential due to mask bias and is accelerated or decelerated. The electron with smaller translational energy than mask bias is reflected and neutralizes the wafer and that with larger one cannot contribute to neutralization. So, if we supply minus bias on the mask, a large number of electron return to the wafer.

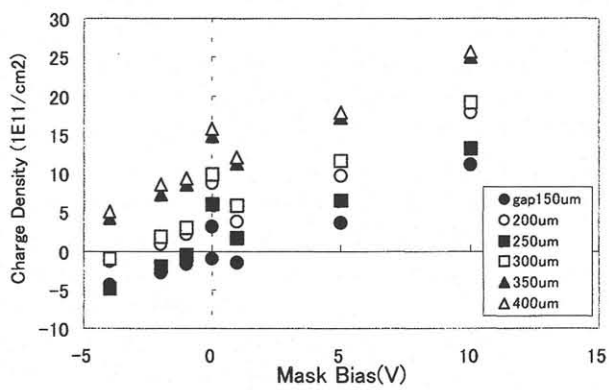

Fig.4. Mask bias dependence of charge density. Phosphorous ion was implanted to a dose of $2x10^{13}cm^{-2}$ into SiO_2 film with 300-nm thickness.

The other possibility is that electron ejected from the mask contributes to neutralization of the wafer. Due to some factors (for example, collision of implanted ion or electron ejected wafer with the mask), the secondary electron ejects from the mask, too. The possibility of the ejection of the electron is function of the mask bias.

3.3 Mask-Wafer Gap Dependence

Figure 5 shows mask-wafer gap dependence of charge density. Charge density depends on the mask-wafer gap. Figure 5 indicates that charge gradually increases with the gap. We speculate that the mask-wafer gap on implantation is so small that conductivity between mask and wafer becomes to be higher. The conductivity depends on the mask-wafer gap. Another speculation is that the potential field may affect the trajectory of the secondary electron from mask and wafer surfaces.

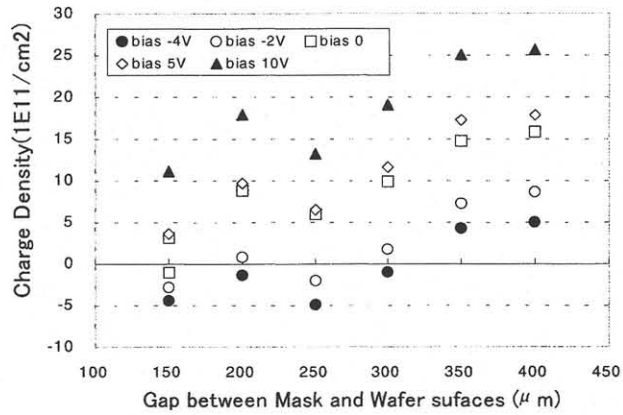

Fig. 5. Gap dependence of charge density. Phosphorous ion was implanted to a dose of $2x10^{13}cm^{-2}$ into SiO_2 film with 300-nm thickness.

4. Conclusions

We present new charge control technology by stencil mask ion implantation. Our experimental observation indicates that charge buildup of a wafer on ion implantation can be quenched without the use of other systems such as secondary electron flood and plasma electron flood systems. The charge density on the wafer after ion implantation can be well controlled by mask bias and distance between mask and wafer. When we use stencil mask ion implantation technology, the charge density is self-controlled. Thus the technology is effective in the manufacturing and engineering of semiconductor devices.

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References

[1] T. Shibata *et al.*, *Technical digest of IEDM2000*, (2000) p.869