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Activation of Implanted Phosphorus Atoms in Silicon Wafers by Infrared Semiconductor Laser Annealing Using Carbon Films as Optical Absorption Layers

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1. Introduction

The activation of impurity atoms implanted into Si wafers using a rapid annealing technology is expected to be more and more significant for the formation of ultra-shallow junctions [1]-[4]. High activation ratio and no serious impurity diffusion are required to fabricate extremely shallow source/drain extension (SDE) region with depth of 10 nm order in metal-oxide-semiconductor (MOS) transistor devices for 45-nm-node and beyond, which cannot be realized by conventional rapid thermal annealing (RTA). Flash lamp annealing (FLA), laser spike annealing (LSA) for several milliseconds or excimer laser annealing for the order of nanoseconds have been developed for this purpose [2]-[4]. We have also proposed an annealing method on the order from 10^{-4} to 10^{-3} seconds using infrared semiconductor laser diodes [5]-[6]. Infrared semiconductor laser is an attractive light source because high power ~10 kW, high efficiency ~50 %, and stable laser diode systems have been already developed. We use a diamond-like carbon (DLC) films as optical absorption layer in order to solve the problem of the low optical absorbance in infrared regions for Si. DLC layers can have a high optical absorbance at infrared region. A high thermal durability to a temperature around 5000 K enables DLC to act as a heat source to the underlying Si substrates to be annealed at a high temperature [8].

In this paper, we report annealing of Si implanted with phosphorus atoms using infrared semiconductor laser. We demonstrate effective activation of dopant atoms and low electrical resistance. We also report that initial phosphorus in-depth profiles were not significantly changed by laser annealing.

2. Experimental

Thin layers of silicon dioxide (SiO_2) with a thickness of 7.9 nm were grown over p-type Si(100) substrates with a resistivity of 5-15 Ωcm prior to an implant operation as a screen oxide layer. The ion implantation of phosphorus impurities using PH_x^+ ions was conducted. The ion energy was 7.5 keV. The dose was $5x10^{14}$, $1x10^{15}$, and $1.5x10^{15}$ cm^{-2}. Pre-amorphization of junctions by Ge or Si implantation (PAI) was not carried out. Then, DLC films with a thickness of 200 nm were formed on the Si surface by unbalanced magnetron sputtering (UBMS), with Ar gas [8]. Optical measurement revealed that the DLC/Si had an optical absorbance of 85 % at 940 nm. Samples were normally irradiated with a fiber coupled continuous wave (CW) laser diode with a wavelength of 940 nm at a power of 19-23 W in air at room temperature. The power distribution of the beam had a Gaussian-like profile. The diameter of the beam was 180 μm. The peak power density was 66.5-80.5 kW/cm^2 at the sample surface. Samples were mounted on an X-Y stage driven by linear motors at a constant velocity of 7 cm/s in the Y direction. Thus, the dwell time of the laser beam, which is defined as (beam size)/(scanning velocity), was 2.6 ms. The stage was also moved with a 50 μm step in the X direction. After laser irradiation, the carbon layer was removed by oxygen plasma treatment. And then, the screen oxides were also removed by HF solutions.

Raman scattering spectral measurements were conducted in order to estimate crystalline states at the Si surface. Then, the sheet resistance measurements were carried out. The phosphorus concentration in-depth profile was measured by secondary ion mass spectroscopy (SIMS) analysis.

3. Results and Discussion

Figure 1 shows the results of Raman scattering measurements for the sample implanted at a dose of $1.5x10^{15}$ cm^{-2}. The laser irradiation was conducted at a power of 19, 20, 22, and 23 W. As-implanted sample has a higher intensity at wave number of 400-500 cm^{-1} than the laser irradiated samples. The broad band around 480 cm^{-1} for as-implanted sample indicates that the Si surface was partially amorphized by the ion implantation. As the laser power increased, the tail state at lower wave number than 520 cm^{-1} decreased. It means that the recrystallization exceeded by increasing the power of laser irradiation. The amorphized surface regions were almost completely crystallized for laser annealing at 22 W (77 kW/cm^2).

Figure 2 shows the changes in sheet resistance of the samples at doses of $5x10^{14}$, $1x10^{15}$, and $1.5x10^{15}$ cm^{-2} with the laser power of 19-23 W. The sheet resistance decreased to 424 and 242 Ω/sq for $5x10^{14}$ and $1.5x10^{15}$ cm^{-2}, respectively, as the laser power increased. It almost leveled off for the laser power between 21 and 23 W for the both cases of $1x10^{15}$ and $1.5x10^{15}$ cm^{-2}. These results made us believe that phosphorus impurities were well activated at a laser power above 21 W (73.5 kW/cm^2).

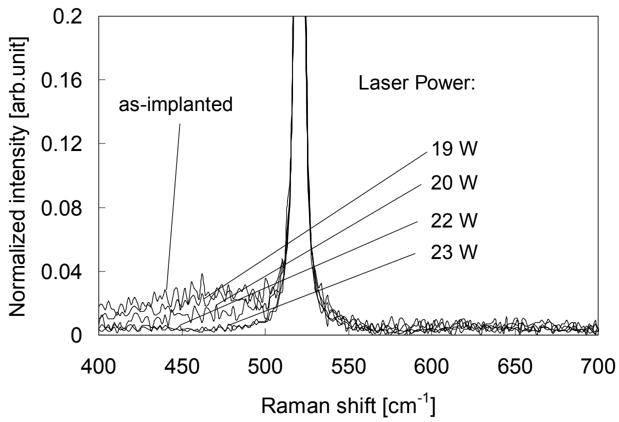

Fig. 1 Raman scattering spectra of the surface regions for $1.5\text{x}10^{15}$-cm^{-2}-as-implanted and laser annealed at a power of 19, 20, 22, and 23 W.

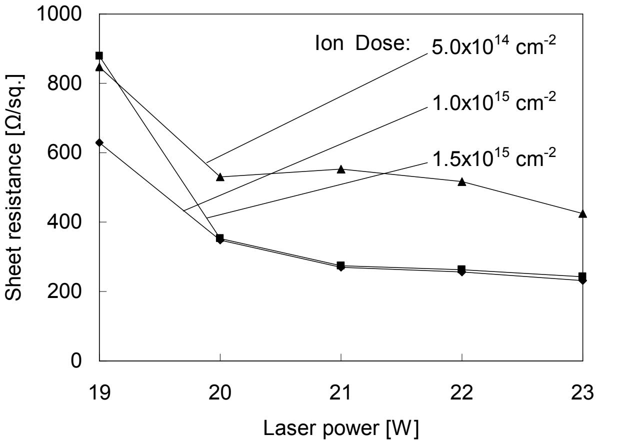

Fig. 2 Changes in sheet resistance with laser power of 19-23 W for $5\text{x}10^{14}$, $1.0\text{x}10^{15}$, and$1.5\text{x}10^{15}$ cm^{-2} phosphorus implantation at 7.5 keV.

Figure 3 shows the phosphorus atoms in-depth profiles at a dose of $1.5\text{x}10^{15}$ cm^{-2} at 7.5 keV and laser annealed at 0 (as-implanted), 20, 22, and 23 W. The depth at the phosphorus concentration of 10^{18} cm^{-2}, which is called as a junction depth, was 48 nm for the as-implanted sample. SIMS results revealed that the effective dose of phosphorus atoms was $1.1\text{x}10^{15}$ cm^{-2} for as-implanted sample. About 27 % of implanted phosphorus atoms were recoiled or trapped in the screen oxide. For the laser power of 23 W, the effective dose was decreased to $9.1\text{x}10^{14}$ cm^{-2}. About 17 % of implanted phosphorus atoms in Si were lost. It might be caused by mainly out diffusion into the screen oxide. Phosphorus concentration at the depth of 0-30 nm was slightly decreased by the laser irradiation. However, the junction depth was not changed for the sample annealed at 23 W. In other words, there were no serious changes in phosphorus profiles.

4. Conclusions

940-nm-CW laser annealing with 200-nm-thick DLC optical absorption layer was applied to activation annealing

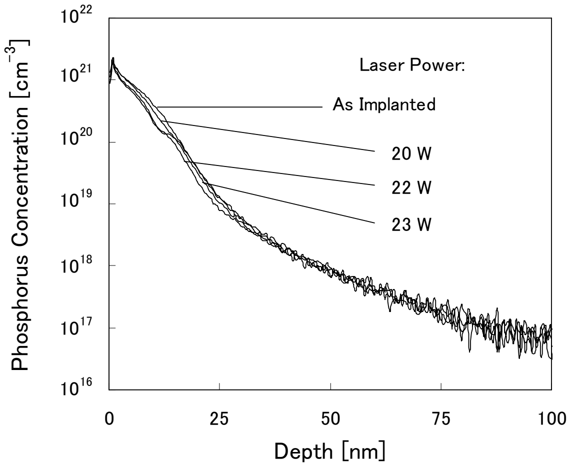

Fig.3 SIMS profiles of phosphorus atoms implanted into Si at a dose of $1.5\text{x}10^{15}$ cm^{-2} at an ion energy of 7.5 keV. Laser annealing was carried out at a power of 0(as-implanted), and 20-23 W (70-80.5 kW/cm^2).

of Si wafers ion-implanted with phosphorus atoms. The ion implantations were carried out at an ion energy of 7.5 keV at a dose of $5\text{x}10^{14}$-$1.5\text{x}10^{15}$ cm^{-2} via screen oxide films with thickness of 7.9 nm. The initial junction depth was 48 nm. The wafers were annealed by the laser irradiation at a power density of 66.5-80.5 kW/cm^2 and a dwell time of 2.6 ms. The amorphized region by ion implantation was almost completely recrystallized at a laser power above 22 W. By the laser annealing at 23 W, the sheet resistances markedly decreased to 242 Ω/sq for a dose of $1.5\text{x}10^{15}$ cm^{-2}. SIMS measurements revealed that the CW laser annealing hardly changed the phosphorus profiles. The present annealing method is expected to be applied to formation of ultra-shallow junctions for future MOS devices.

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References

[1] M. Mehrotra, J. C. Hu and M. Rodder: IEDM Tech. Dig. 1999, p.419.
[2] T. Ito, K. Suguro, M. Tamura, T. Taniguchi, Y. Ushiku, T. Iinuma, T. Itani, M. Yoshioka, T. Owada, Y. Imaoka, H. Murayama, and T. Kusuda: Ext. Abstr. 3rd Int. Workshop on Junction Technol. 2002, p. 23.
[3] A. Shima and A. Hiraiwa: Jpn. J. Appl. Phys. **45** (2006) 5708.
[4] K. Goto, T. Yamamoto, T. Kubo, M. Kase, Y. Wang, T. Lin, S. Talwar and T. Sugii, IEDM. Tech. Dig. 1999, p. 931.
[5] T. Sameshima and N. Andoh: Jpn. J. Appl. Phys. **44** (2005) 7305.
[6] N. Sano, M. Maki, N. Andoh and T. Sameshima: Jpn. J. Appl. Phys. **46** (2007) 1254.
[7] T. Sameshima and N. Andoh: Mat. Res. Soc. Symp. Proc. **849** (Boston, 2004) KK9.5.
[8] S. Yang, D. Camino, A. H. S. Jones and D. G. Teer: Surf. Coat. Technol. **124** (2000) 110.