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XeCl Excimer Laser-Doping of Silicon Using Phosphorus and Boron Film as a Diffusant Source

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A new method of fabricating ultra-shallow junctions has been developed in which plasma-deposited boron or phosphorus dopant film is coated on silicon wafers, followed by XeCl excimer laser irradiation. Junction depths were 0.03 µm to 0.3µm depending on laser-beam energy density and the material used for the dopant layer. A sheet resistivity as low as 10Ω/□ for p^+ junctions and 77Ω/□ for n^+ junctions was obtained. Diodes fabricated in the laser-doped layer showed I-V characteristics with a quality factor of 1.3 and low backward leakage current, indicating that rapid melt and regrowth in the present process does not cause any serious defect in doped layer.

1. INTRODUCTION

Ultra-shallow junctions have been receiving much attention recently because submicron CMOS transistors and TFTs on insulating substrates require source/drain contacts on the order of 0.1µm. With the conventional ion implantation technique, it is difficult to form such a shallow junction, particularly a p^+ ultra-shallow junction, because of the difficulty of precisely controlling a low energy ion beam. As an alternative to ion implantation, excimer laser doping is a very promising technique for forming shallow junctions in submicron devices.

Carey et al.(1) reported the GILD (gas immersion laser doping) process in which the silicon wafers to be doped with boron were irradiated in B_2H_6 gas by XeCl excimer laser pulses. This process is characterized by pyrolysis only of dopant gas at the laser irradiated surface and liquid phase diffusion of the dopant in molten silicon. Carey et al. obtained peak boron concentrations from $5x10^{19}cm^{-3}$ to $5x10^{20}cm^{-3}$ depending on the number of laser pulses, while reporting that the junction depth varied from 0.08µm to 0.16µm depending on the laser energy density. Kato et al.(2) recently carried out similar laser doping experiments, and reported that, with the combination of an ArF excimer laser and BF_3 gas, very shallow junctions can be formed to depths of 0.04µm to 0.2µm depending on the number of laser pulses used, which is in contrast to Carey's results.

Here we report a new technique for fabricating ultra-shallow p^+ and n^+ junctions. The technique is characterized by two steps in which dopant layers, usually overlaid with SiO_2 film, are first depositd on a silicon wafer by plasma CVD, then exposed to XeCl excimer laser pulses. We investigated the relationship between the characteristics of laser doped layer and the irradiation conditions.

2. EXPERIMENTAL

The structure of the samples is shown in Fig. 1. An excimer laser emitting 35ns-long 300mJ pulses was used to melt the silicon surface just beneath the dopant film. The 6x20mm laser beam was collimated to a beam size from 1x3mm to 3x10mm on the sample surface depending on the distance between the sample and the quartz lens mounted on a beam scanning stage. The energy fluence on the sample, after being reduced by the beam scanning optical system, was typically $1.0J/cm^2$ to $2.5J/cm^2$.

(111) oriented n-type and p-type silicon wafers with a resistivity of 40 to 100Ω.cm were used to fabricate samples for the sheet resistance measurements of the p^+ layer and the n^+ layer, respectively. Dopant films were

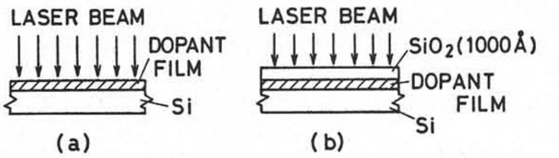

Fig. 1 Cross section of samples used for laser-doping.

deposited by glow discharge decomposition of dopant gases. In this work, B_2H_6 and PH_3 gases diluted to 1% with Ar were introduced into a diode-type plasma reactor. The deposition time, deposition pressure, substrate temperature and rf power were 10min, 200mTorr, 150°C and 5W, respectively. Because deposited boron and phosphorus films are easy to combine with water in air, some of the samples were coated with dopant film followed by a deposit of SiO_2 1000A thick achieved by glow discharge decomposition of an $N_2O/SiH_4/Ar$ gas mixture. The deposition temperature was 150°C or 300°C. The gas pressure and the rf power were 200mTorr and 5W, respectively.

The samples were then placed in a laser processing chamber and irradiated in vacuum, in inactive gas, or even in air, by a pulsed laser beam impinging normal to the sample surface. After laser irradiation, layers of dopant and SiO_2/dopant were removed. Gap cells for measurements of sheet resistivity and carrier concentration were fabricated in the doped area on the surface. Photolithography and etching of evaporated aluminum defined electrodes 300μm long with 30μm spacing. In order to determine the carrier concentration profiles, the gap cells were subjected to gas phase step etching in CF_4 plasma. About 100Å were etched each step and sheet resistivity was measured after each step.

To evaluate the electrical characteristics of p^+-n junctions, diodes were fabricated using the process described below. N-type (111) oriented silicon wafers with a resistivity of 2-10Ω.cm were coated with boron films, followed by the deposition of SiO_2 under the conditions mentioned earlier. After laser-doping with a stationary excimer laser beam of various pulses, the SiO_2/dopant layer was washed away in SO-1 etchant. A mesa structure including a p^+-n junction was fabricated by CF_4 plasma etching, followed by deposition of SiO_2 film. Contact holes were then opened and evaporated aluminum electrodes were formed using photolithography. The whole back surface of the sample was doped with phosphorus using the present laser doping technique to a sheet resistivity of 10 to 100Ω/□ to insure ohmic contact, followed by evaporation of aluminum.

3. RESULTS AND DISCUSSION

Figure 2 shows the dependence of sheet resistivity on laser energy density for p^+ and n^+ layers produced by irradiating Si wafers coated with dopant films: SiO_2 passivation film was not overlaid. As is shown in the figure, the sheet resistivity decreased rapidly up to 0.4J/cm^2 for the boron-doped layer and up to 0.6J/cm^2 for the phosphorus-doped layer. Both curves level off above the threshold melting energy at the values 30Ω/□ for the p^+ layer and 77Ω/□ for the n^+ layer. It should be noted that the threshold energy for boron-doped p^+ layer is much lower than that for the phosphorus-doped n^+ layer. This can be explained by the fact that the reflectivity at 308nm for the boron-coated surface is 14%, much less than the reflectivity of 58% for the phosphorus-coated surface, resulting in a more efficient conversion of laser beam energy into heat.

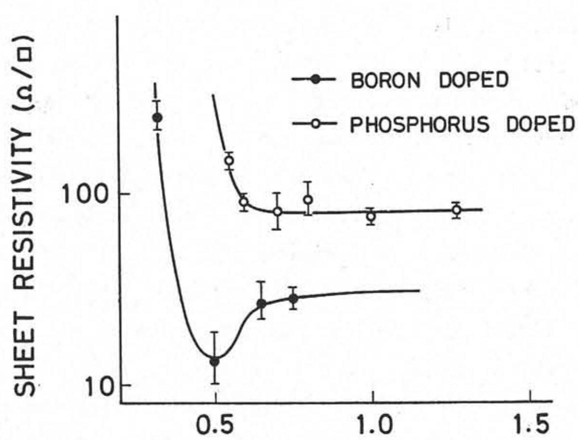

Fig. 2 Sheet resistivity of p^+(solid circles) and n^+(open circles) layer produced by irradiating boron/Si and phosphorus/Si surface, respectively, with 10 pulses of XeCl excimer laser beam.

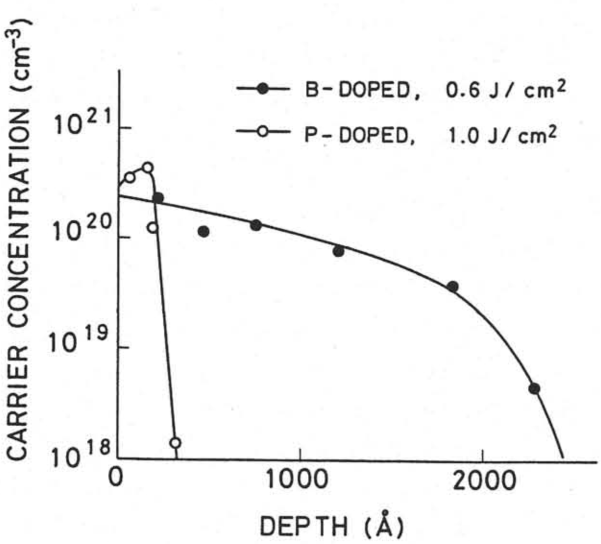

Fig. 3 Carrier concentration depth profiles for p^+(solid circles) and n^+(open circles) layers produced from boron/Si and phosphorus/Si samples, respectively.

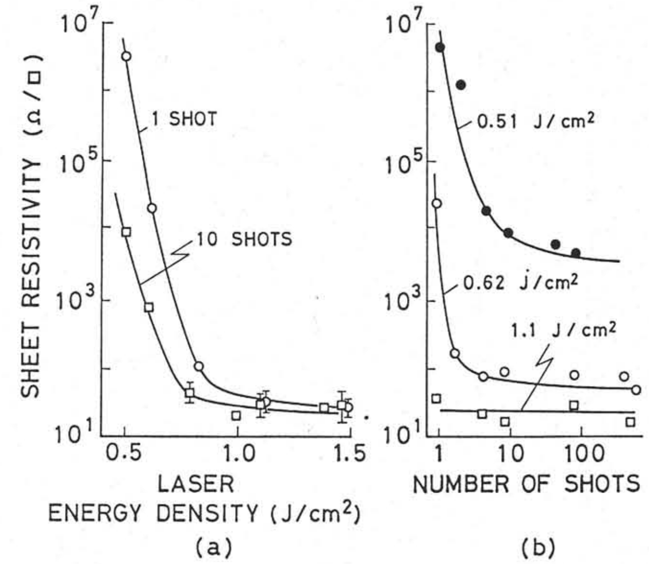

Fig. 4 (a) The dependence of sheet resistivity on laser energy density(a), and number of laser shots(b). SiO_2(1000Å)/boron-coated Si was exposed to a stationary pulsed laser beam.

The depth profiles of carrier concentration obtained by the step-etching resistivity measurements mentioned earlier are shown in Fig. 3. Junction depth depended on the laser energy density and varied from 0.05μm to 0.3μm for boron-doped and 0.03μm to 0.1μm for phosphorus-doped layers, respectively. The carrier concentration can be estimated to be $2x10^{20}cm^{-3}$ from the resistivity, the product of sheet resistivity and the junction depth (X_j), by applying the value to Irvin's results(3).

The similar results were obtained for samples with SiO_2-overlaid dopant films. The use of SiO_2 film as a passivation layer provides many advantages. Since both boron and phosphorus films produced in a glow discharge cannot be exposed to air for a long period of time, additional SiO_2 coating is needed to protect the dopant films from moisture in air. SiO_2 passivation film can also stop the introduction of undesirable atoms into molten silicon during irradiation in ambient gas. Another advantage of using SiO_2 passivation film is that the laser energy density for optimum doping can be greatly reduced: a thickness of 500Å satisfies the anti-reflection condition requirement.

Sheet resistivity plotted against laser energy density and against number of pulses is shown in Fig.4(a) and Fig.4(b), respectively. In Fig.4(a), levelling off of the sheet resistivity occurs at 0.8J/cm^2, a slightly higher energy than that for samples without overlaid SiO_2 film, because of the higher reflectivity (31.5%) of SiO_2 (1000Å)/boron-coated surface compared with that (14%) for boron-coated surface in Fig. 2. It is interesting to note that sheet resistivity does not depend on the number of pulses with an energy higher than 0.6J/cm^2, the threshold melting energy. Even a single shot of a 1.1J/cm^2 laser beam can produce a doped layer with a resistivity as low as 30Ω/□. This indicates that doping does not occur any longer after a single shot of the laser beam, because dopant atoms are consumed and there is a simultaneous increase in surface reflectivity. The junction depth for a single shot irradiated layer was measured using SIMS as 733Å for 0.62J/cm^2 and 3260Å for a 1.1J/cm^2 beam as is shown in Fig. 5.

The p^+-n junctions were evaluated by fabricating diodes. Figure 6 shows the I-V characteristics of a diode formed in the p^+ layer doped with boron by exposure to a single shot of a laser beam with 0.83J/cm^2 energy density. Although the diode was not subjected to any annealing, the quality factor (n value) in forward bias characteristics is 1.3 and reverse bias current is 40nA/cm^2. The rapid melt and regrowth of silicon on exposure to a high energy laser pulse does not cause any serious defect in the laser doped layer.

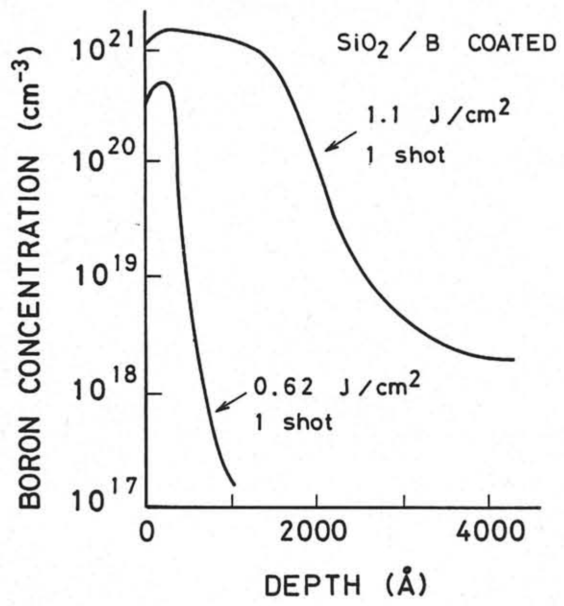

Fig. 5 Dopant profiles measured by SIMS.

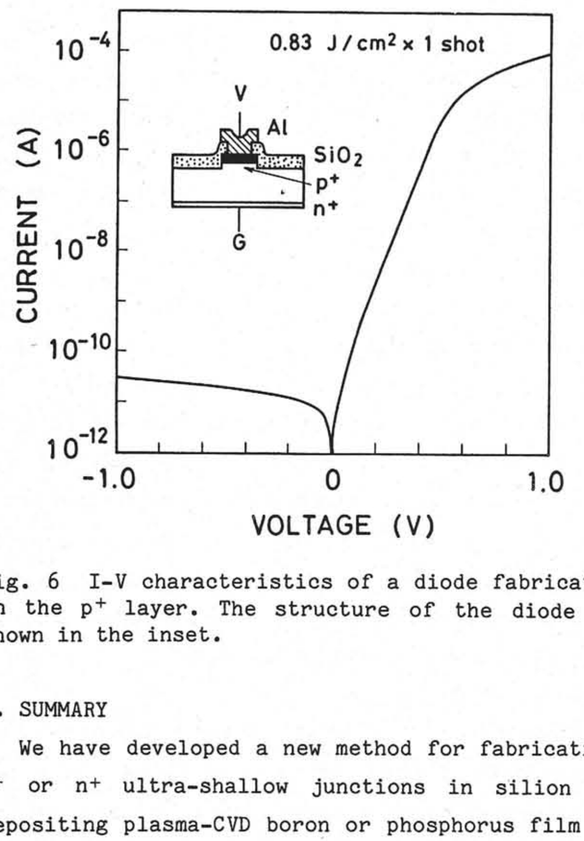

Fig. 6 I-V characteristics of a diode fabricated in the p^+ layer. The structure of the diode is shown in the inset.

4. SUMMARY

We have developed a new method for fabricating p^+ or n^+ ultra-shallow junctions in silion by depositing plasma-CVD boron or phosphorus film on silicon substrates followed by XeCl excimer laser irradiation. When a passivation film overlaid on dopant film is used, the irradiation can be done even in air.

Junction depth is 0.03μm to 0.3μm depending on the laser-energy density and the material used as a dopant. Sheet resistivity of laser-doped layer does not depend on the laser energy density and the number of pulses when dopant-coated Si was irradiated with a beam of above threshold melting energy. Boron atoms are introduced deeper into silicon than phosphorus atoms with laser beams of the same energy intensity. This is partly due to the reduced reflectivity of boron or a SiO_2/boron coated silicon surface. The minimum sheet resistivity was 77Ω/□ for a phosphorus-doped layer and 10Ω/□ for a boron-doped layer.

Diodes fabricated using the present laser doping technique showed nearly ideal I-V characteristics with a quality factor of 1.3, indicating that rapid melt and regrowth during a time less than several hundred nanoseconds in the laser doping process does not cause serious defects in the doped layer.

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