

Impurity Doping into Single and Poly Crystalline Silicon by a Large Area Ion Doping Technique

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We have developed a low energy broad (370mm ϕ) ion beam doping technique without mass separation and beam scanning. Phosphorus or boron ions were implanted into single and poly crystalline Si with an acceleration voltage of 1.5kV. We confirmed that resistance uniformity in five pieces of 3in.-Si wafers simultaneously doped by this technique was ± 3.44 percent for boron and was ± 4.22 percent for phosphorus doping. This technique enables to fabricate large area devices such as thin film transistors using a-Si and poly-Si.

1. INTRODUCTION

It is of great importance to study and develop deposition, photolithography, etching and doping techniques which enables these treatments homogeneously over large area, in order to fabricate large area devices such as switching TFT arrays (250mm x 250mm) of liquid crystal displays¹⁾, image scanners, etc. In doping technique, the ion implantation technique with mass separation has been widely applied to dope impurities into silicon substrates. However, this technique has a disadvantage for doping over a large area. Several workers studied the ion implantation technique without mass separation, using a DC glow discharge ion source^{2,3)}, Freeman-type ion source with beam bender⁴⁾ and micro wave ion source⁵⁾. The doping areas of these studies were 20cm²²⁾ and 3in.-wafers³⁾. These doping techniques are not applicable to fabricate such large area devices.

We have been studying the doping of impurities into Si substrates by a low energy broad ion beam doping^{6,7)}. In this

technique, doping gases are discharged by externally c-coupled rf power and magnetic fields. Ions extracted from discharged gases are implanted into semiconductors without mass separation and beam scanning. Recently we have developed an apparatus with a 450mm diameter discharge chamber. We confirmed a large area doping into silicon substrates using this technique. For the application of the device fabrication, we investigated the application to the poly-Si TFT¹⁾ process.

2. LARGE AREA ION DOPING APPARATUS

Figure 1 shows a schematic drawing of a large ion doping apparatus. This apparatus consists of a plasma chamber made of glass (450mm diameter and 500mm height) and a sample chamber. A pair of electrodes (150mm x 400mm) is attached to the outside of the plasma chamber. These electrodes supply rf (13.56MHz) power into the plasma chamber by capacitance coupling. A capacitance between these electrodes is calculated to be 1.2pF. A magnetic coil is set at the outside of the plasma chamber to

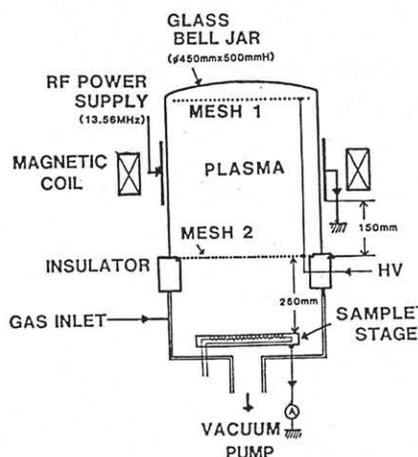


Fig.1. A schematic drawing of a large area ion doping apparatus.

supply an axial magnetic field. Gas is discharged at a pressure of about $1.0-0.5 \times 10^{-3}$ Torr. Ions diffused from the plasma region to an aperture (370mm ϕ) with mesh 2 are accelerated by a potential difference (V_i) between mesh 2 and a sample stage (320mm ϕ) in the sample chamber and are radiated onto samples. A potential of the plasma between mesh 1 and mesh 2 is equal to V_i . So sputtering of these electrodes does not occur. However, since hydrogen radicals or ions from discharged dilution gas may react with these meshes, chemically stable metal of pure gold was coated on these meshes.

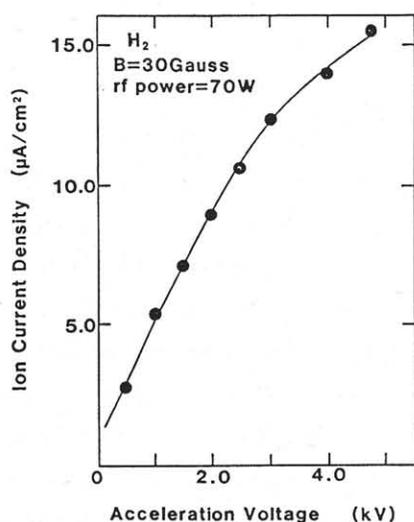


Fig.2. Acceleration voltage (V_i) dependence of ion current density (J_i) at the sample stage.

Figure 2 shows V_i dependence of ion current density (J_i) in account of secondary electron emission. We used hydrogen as discharge gas. The discharge conditions were as follows; H_2 flow rate was 120 sccm, the input rf power was 70W, and the magnetic field intensity (B) at the center of the plasma chamber was 20 Gauss. The value of B will be discussed in correlation with doping uniformity. From Fig. 2, the value of J_i at V_i of 1.5 kV was $10 \mu A/cm^2$, and J_i was seemed to be saturated at above V_i of 4.0 kV.

3. DOPING UNIFORMITY

We measured the optical emission spectra (OES) and spatial uniformity of emission intensity from discharged N_2 gas at four points in the plasma chamber⁸⁾. The emission intensity from discharged N_2 gas without a magnetic field is about 1/4 that of those with 30 Gauss. This result suggests that a magnetic field of about 30 Gauss is effective to enhance the discharge of gas, though the magnetic field intensity relating to an electron cyclotron resonance at 13.56 MHz is 4.8 Gauss. We confirmed that the spatial uniformity of emission intensity was obtained to be ± 5 percent with 30 Gauss. As a magnetic field intensity increases to 50 Gauss, uniformity of emission intensity becomes to be ± 75 percent. From these results, we selected magnetic fields to an intensity of 10-40 Gauss at the center of the magnetic coil, in order to dope impurities homogeneously over a large area.

To check doping uniformity, five pieces of 3 inch <100> Si wafer were set on the sample stage and were doped with boron or

Table I Doping conditions in this work

| | |
|--------------------------|--|
| doping gas | 0.5% B_2H_6 in H_2 or 1.0% PH_3 in H_2 |
| input rf power | 75-150 W |
| magnetic field | 30 Gauss (at the center of plasma chamber) |
| ion acceleration voltage | 1.5 kV |
| ion current density | $10 \mu A/cm^2$ |
| substrate temperature | room temperature |

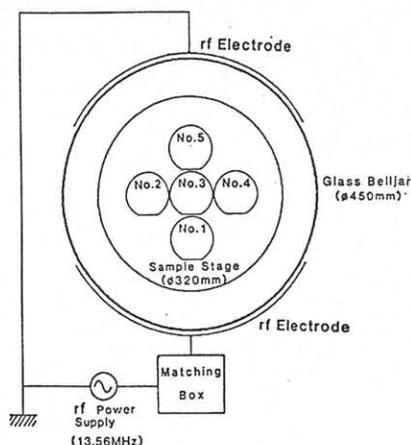


Fig.3. A schematic drawing of cross sectional view of the plasma chamber and the sample stage. Position and sample No. of each wafer are also shown.

phosphorus as shown in Fig. 3. We used n-type Si with resistivity of 8-10 Ω cm for boron doping (No. 1-B, 2-B, 3-B, 4-B, 5-B), and p-type Si with resistivity of 5-8 Ω cm for phosphorus doping (No. 1-P, 2-P, 3-P, 4-P, 5-P). The wafer, sample number No.3-B, 3-P, was set at the center of the sample stage. Ions containing dopants were irradiated under the conditions as shown in Table I. After the irradiation of ions, wafers were annealed at 900°C for 30 minutes in N₂ atmosphere. After this annealing, simultaneously implanted hydrogen atoms were diffused out⁷⁾. We measured the sheet resistances (R_S) of these doped wafers by an in line four point probe. The number of measurement points per one wafer was forty-five. Table II shows the average sheet resistances (\bar{R}_S) and the standard deviations of sheet resistances normalized by \bar{R}_S ($\sigma(R_S)/\bar{R}_S$). We confirmed in one doping cycle that the \bar{R}_S of these wafers were 296.7 Ω /sq and 43.89 Ω /sq, and $\sigma(R_S)/\bar{R}_S$ were ± 3.44 percent and ± 4.22 percent, for boron and phosphorus doping, respectively.

4. DOPING CONTROLL

Figure 4 and 5 show sheet resistances and doping uniformity in one wafer of boron

Table II Average sheet resistance (\bar{R}_S) and uniformity ($\sigma(R_S)/\bar{R}_S$) of boron or phosphorus implanted c-Si wafers annealed in N₂ at 900°C for 30min. Ion irradiation time were 900sec for boron and 600sec for phosphorus. Wafers were set on the sample stage as shown in Fig.3.

| Sample Number | \bar{R}_S (Ω /sq) | $\sigma(R_S)/\bar{R}_S$ (%) | Sample Number | \bar{R}_S (Ω /sq) | $\sigma(R_S)/\bar{R}_S$ (%) |
|---------------|-----------------------------|-----------------------------|---------------|-----------------------------|-----------------------------|
| No. 1-B | 304.5 | 2.34 | No. 1-P | 43.12 | 3.60 |
| No. 2-B | 298.3 | 3.20 | No. 2-P | 42.51 | 3.46 |
| No. 3-B | 296.2 | 2.47 | No. 3-P | 43.36 | 3.33 |
| No. 4-B | 297.1 | 3.47 | No. 4-P | 44.59 | 3.81 |
| No. 5-B | 287.3 | 2.88 | No. 5-P | 45.78 | 2.23 |
| Total | 296.7 | 3.44 | Total | 43.89 | 4.22 |

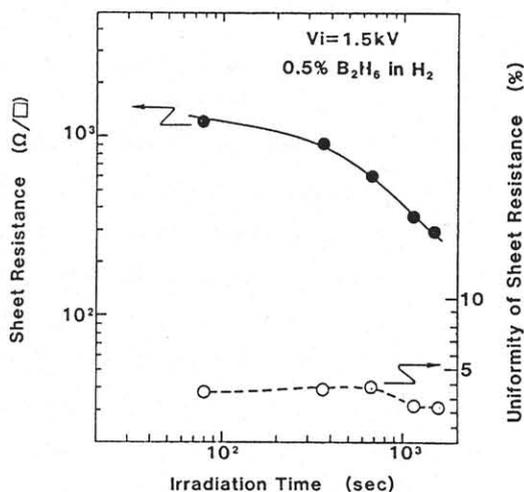


Fig.4. Sheet resistance as a function of ion irradiation time for boron implanted c-Si annealed in N₂ at 900°C for 30min. Doping gas was 0.5% B₂H₆ in H₂, V_i was 1.5kV and J_i was 10 μ A/cm².

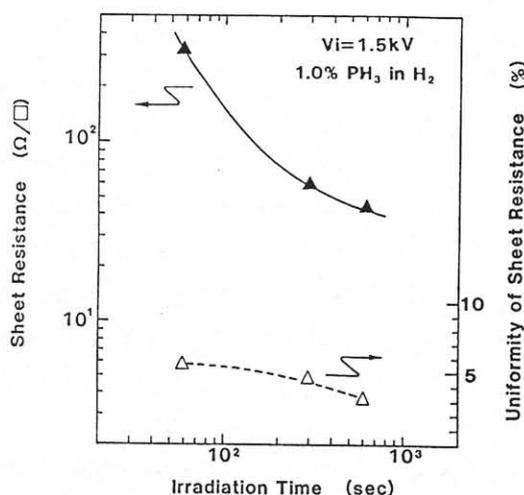


Fig.5. Sheet resistance as a function of ion irradiation time for phosphorus implanted c-Si annealed in N₂ at 900°C for 30min. Doping gas was 1.0%PH₃ in H₂, V_i was 1.5kV and J_i was 10 μ A/cm².

and phosphorus implanted layers as a function of ion irradiation time (t_i). The values of t_i were calculated by the normalization of irradiation time in experiments to the irradiation time at J_i of $10\mu\text{A}/\text{cm}^2$. We obtained that doping uniformity was $\pm 2-5$ percent at each dose level and range of R_S was about $300-1200\Omega/\text{sq}$ and $40-400\Omega/\text{sq}$, for boron and phosphorus doping, respectively.

In case of t_i of 1178sec; the right point in Fig.4, total boron dose was calculated to be $3.1 \times 10^{15} \text{cm}^{-2}$ by an integration of SIMS profile⁸⁾. For the device fabrication, we obtained applicable value of R_S at this dose level. However, the concentration of boron atoms was $3 \times 10^{21} \text{cm}^{-3}$ near the surface; 5nm in depth, we confirmed no boron-boron bonding signal by X-ray photoelectron spectroscopy (XPS) analysis. We also confirmed very few phosphorus-phosphorus bonding signal from phosphorus doped silicon wafer; the right point in Fig. 5.

5. APPLICATION TO POLY SILICON DOPING

We applied this technique to poly-Si doping. In fabrication of large area poly-Si TFT¹⁾, it is important to lower process temperature. So we measured R_S of implanted poly-Si films which were annealed at several annealing temperatures (T_{an}). The poly-Si films of 300nm thickness were deposited on SiO_2/Si substrates by low pressure chemical vapour deposition at 610°C . Fig. 6 shows T_{an} dependences of sheet resistance. R_S of boron doped films decreased monotonously with T_{an} . On the other hand, R_S of phosphorus doped films decreased critically at $700-800^\circ\text{C}$. We obtained the same results from poly-Si films on quartz⁷⁾. The values of R_S were $2.36\text{k}\Omega/\text{sq}$ for boron doping and $3.58\text{k}\Omega/\text{sq}$ for phosphorus doping at T_{an} of 800°C .

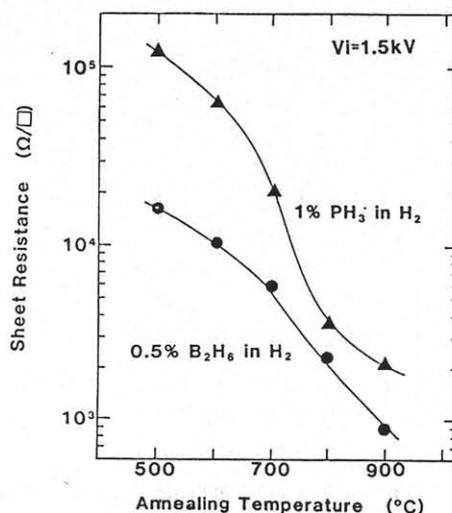


Fig.6. Sheet resistance as a function of annealing temperature for phosphorus or boron implanted poly-Si annealed in N_2 for 30min. Ion irradiation time were 900sec for boron and 300sec for phosphorus.

6. SUMMARY

The ion current density was $10\mu\text{A}/\text{cm}^2$ and the doping uniformity into five silicon wafers was ± 3.44 percent for boron and ± 4.2 percent for phosphorus 1.5kV-ion doping using the large area doping apparatus. We think this technique is applicable to fabrications of large area devices such as poly-Si TFT arrays.

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