Effect of CW Laser Annealing on Silicon Surface for Application of Power Device

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Abstract—As application of re-activation of backside on power device Insulated Gate Bipolar Transistor (IGBT), laser annealing was employed to irradiate amorphous silicon substrate, and resistivities were measured using four point probe measurement. For annealing the amorphous silicon two lasers were used at wavelength of visible green (532 nm) together with Infrared (793 nm). While the green laser efficiently increased temperature at top surface the Infrared laser reached more deep inside and was effective for melting the top surface. A finite element method was employed to evaluate time dependent thermal distribution in silicon substrate.

Keywords—laser, annealing, silicon, recrystallization, thermal distribution, resistivity, finite element method, absorption, melting point, latent heat of fusion.

I. INTRODUCTION

POWER Device is the basis of power electronic technology in rapid development with an environmental problem. A power device IGBTs (Insulated gate bipolar transistor) are one of key components of an inverter for hybrid vehicles, and used as a switching device. One characteristic factor is IGBTs consisting of p-type collector on the backside to induce holes during on state to decrease on resistance of the device, as shown in Figure 1. As down sizing the device, it is required to re-activate the backside of IGBT after implanting boron atoms to fabricate p-type layer.

In this study, two laser were employed as backside activation technique of power device IGBTs by both visible green and Infrared lasers. The two wavelength lasers irradiated the surface of amorphous silicon with the high scan speed of 300 m/min. A finite element method was employed to estimate the surface temperature irradiated by the two lasers with high scanning speed.

II. EXPERIMENTAL

Amorphous silicon substrate was prepared by ion implantation method; Boron was implanted into 3 inches Si(001) substrate with a dose of $5 \times 10^{15}/\text{cm}^2$ at energy of 60 keV. P ion was also implanted at energy of 60 keV with heavy dose of $1 \times 10^{16}/\text{cm}^2$. The average depth of implanted ions was estimated to be ~250 nm by a simulation method using the Stopping and Range of Ions in Matter (SRIM) [1], [2]. The SRIM calculates the stopping and range of ions into matter using a quantum mechanical treatment of ion-atom collisions.

Two lasers employed to irradiate the amorphous Si substrate were A 532 nm CW laser with a spot size of $10 \times 15 \mu \text{m}$ and laser power ranging from 12 to 18 W, which produced the energy fluency of $24 \rightarrow 36 \text{ J/cm}^2$. A CW near infrared (NIR) laser also simultaneously irradiated at an energy fluency of 32 J/cm² with a wavelength of 797 nm. The two wavelength lasers scanned on the Si substrate with the speed between 300 and 900 m/min. The resistivity was measured by using four point probe method and a finite element method was employed to estimate the surface temperature with time dependency.

III. RESULTS AND DISCUSSION

After laser irradiation on the amorphous Si substrate, resistivity was measured by using four point probe. Table I shows asymmetry along and across the trace of laser scanning.

<table>
<thead>
<tr>
<th>scan speed (m/min)</th>
<th>green laser (W)</th>
<th>NIR laser (W)</th>
<th>resistivity // (Ω/2)</th>
<th>resistivity ⊥ (Ω/2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>18</td>
<td>100</td>
<td>72</td>
<td>65</td>
</tr>
<tr>
<td>300</td>
<td>18</td>
<td>200</td>
<td>64</td>
<td>50</td>
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<td>300</td>
<td>18</td>
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<td>50</td>
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shows resistivities of Boron implanted samples. The resistivity was measured along parallel and vertical to laser scanning direction. Interestingly asymmetric resistivities were obtained on almost all samples irradiated in variety of conditions.

Another example of asymmetric resistivity was obtained on samples irradiated with the scanning speed of 900 m/min. Independent on scanning pitch, higher resistivity was obtained across the trace of laser scanning, as shown in figure 2. After optimizing irradiation conditions, scanning speed of 300 m/min. with the assist of the NIR laser prevented these asymmetric resistivity.

Re-crystallization was verified by Raman spectroscopy. Figure 3 shows raman spectroscopy on laser irradiated area (on scan area, red solid line) and non irradiated area (off scan area, blue solid line) together with Si substrate as a reference. A sharp peak from crystal Si was observed at 520 cm$^{-1}$ along the trace of laser scanning (red solid line) while off scan area shows typical broad peak from amorphous Si. The energy fluency of green laser varied from 12 to 18 W. Independent on energy fluency of green laser, raman spectra indicated re-crystallization after the laser scanning. Whether amorphous silicon melt to re-crystallize on laser scanning?

The PDE solver, FreeFEM3D, solves the following heat transport equation,

$$\rho c_p(T) \frac{\partial T}{\partial t} - \nabla (k(T) \nabla T) = Q(t), \quad (1)$$

where $T$ is the absolute temperature, $c_p(T)$ and $k(T)$ are temperature dependent variables of the specific heat capacity and the thermal conductivity, respectively, $\rho$ is the mass density of target, and $Q(t)$ is the heat generated in the target by both the green and IR laser irradiation, and is defined as

$$Q(t) = (1 - R_g) \alpha_g I_g(t) + (1 - R_{ir}) \alpha_{ir} I_{ir}(t), \quad (2)$$

where $R$ and $\alpha$ are the reflectivity of the surface and the absorption coefficient, respectively, $I(t)$ the power of laser and subscripts of $g$ and $ir$ indicate green and Infrared laser, respectively. The thermal properties are dependent on temperature, and are obtained from literature[3],

$$k(T) = 0.235 + 4.45 e^{-T/(4.247)} \quad (3)$$

$$c_p = 0.81 + 1.3 \times 10^{-4} T - 1.26 \times 10^4 T^{-2} \quad (4)$$

It should be noted that treatment of latent heat of fusion, $L_f$, was included in the simulation. The Dirac function $\delta(t -
melt area stabilized around 7 μm with the laser power between 12 and 18 W.

IV. SUMMARY

As application of re-activation of backside on power device Insulated Gate Bipolar Transistor (IGBT), laser annealing was employed to irradiate amorphous silicon substrate. Resistivities measured using four point probe showed asymmetric resistance, however, scanning speed of 300 m/min, together with the assist of NIR laser. The thermal simulation was employed to estimate surface temperature, showing the size of

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