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The Electrical Characteristics of Recrystallized Silicon by CW CO_2 Laser

(CW CO_2 레이저에 의하여 재결정화된 실리콘의 전기적 특성)

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要 約

본 연구에서는 다결정 실리콘이 CW CO_2 레이저에 의하여 재결정화됨을 보고한다. CW CO_2 레이저의 출력에 따라 재결정화된 실리콘의 표면조직을 SEM으로 관측하고 고유저항값 및 이동도값을 Hall 측정으로부터 구하였다. 연구 결과로부터 다결정 실리콘은 레이저의 출력이 39W일때 부분적으로 액체상태로 되었으며 재결정화된 실리콘의 고유저항 감소 및 이동도 증가는 결정 크기의 증가 및 결정계에서의 전위장벽 감소에 기인됨을 알 수 있었다.

Abstract

In this study, the recrystallization of polycrystalline silicon by CW CO_2 laser is reported. With a variation of CW CO_2 laser power, the surface morphology of recrystallized silicon is observed by SEM and the value of resistivity and mobility is obtained by Hall measurement. From the obtained results, it is concluded that the polycrystalline silicon is locally melted at 39W laser power and the reduction of resistivity and the increase of mobility are caused by the increase of grain size and the reduction of the potentical barrier at grain boundaries.

1. Introduction

Rencently, considerable interests have been given to the recrystallization of polycrystalline silicon on amorphous insulators such as SiO_2, Si_3N_4, or fused silica, because VLSI technology urgently needs some break through along the way to very high density and 3-Dimensional structure [1].

The essential ways to improve the quality of recrystallized silicon lie on the annealing methods, such as strip heater, tungsten halogen lamp, electron beam and laser annealing systems. Among these laser annealing method is more established than other methods because of local heating and efficient processing. It is well known that there are two methods of laser annealing. One of the two methods changes the surface of semiconductor to liquid phase state when it is exposed under the pluse laser source and the other is to take adavantage of the CW laser source which does not melt the surface of the semiconductor. In the second method, crystalline semiconductor is grown by solid phase epitaxy where the interface is con-

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trolled by multiple rearrangements of dangling bonding pairs and these rearrangement process is activated by the bond breaking events. particularly, some authors reported that the range of grain size growth is from 500 Å to the order of μm with CW laser annealing method. Therefore, it is possible to fabricate discrete devices on these grains [2].

In this study, we have studied the electrical characteristics and surface morphology after CW CO_2 laser annealing process. Hall and SEM observations are performed to confirm the reduction of resistivity and the increase of mobility due to the enlargement of grain size and the reduction of potential barrier at the grain boundaries.

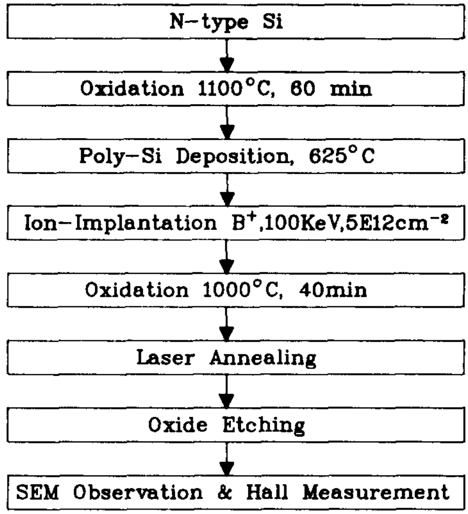

Fig. 1. The flow chart of experimental.

II. Experimental procedures

We carried out the experimental procedures as shown in Fig.1. The substrate used is N-type doped, (100) CZ silicon and its resistivity is 2-5Ω-cm. At first, we oxidized the samples at 1100°C for 1 hour in O_2 ambient to grow a thermal oxide of 1000 Å. After the oxidation process, 5000 Å thick polycrystalline silicon film is deposited on the SiO_2 in an LPCVD reactor at 650°C and next, in order to study the electrical characteristics, Boron is implanted into the thick polycrystalline silicon film at 100 KeV with the dose of 5E12 cm^{-2}. In order to reduce the reflectvity of the surface during CW CO_2 laser annealing, a second oxidation process is carried out at 1000°C for 0.4 hour in O_2 ambient. The second oxide thickness is 500 Å. The structure of the prepared samples is shown in Fig.2.

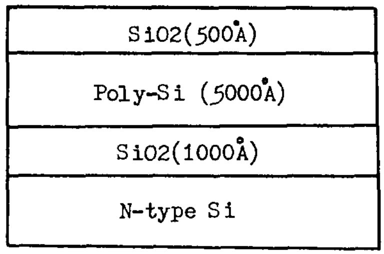

Fig. 2. Structure of samples.

Prepared samples are irradiated with CW CO_2 laser to recrystallize the polycrystalline silicon film. A schematic diagram of the laser annealing system is shown in Fig.3. In Fig.3, we used ZnSe lens with 127mm focal length. The beam scanning along X direction is performed by a step motor and y direction is scanned by the movement of micrometer. The calculated beam radius is 70 μm, but the exact measured value is about 160 μm (3). Scanning speed is 4.3 mm/sec, which is a stable condition for SiO_2 capped structures (4). We obtained 10mmx8mm recrystallized area with successive parallel scanning while moving micrometer

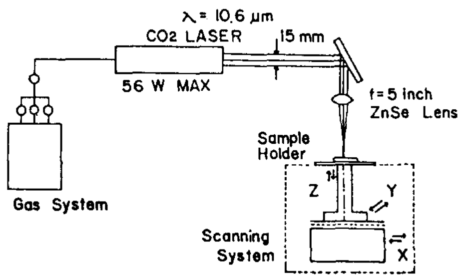

Fig. 3. A schematic digram of laser annealing system.

along Y-direction by 250 μm step distance.

It is to be noted that it is rather difficult to obtain a high quality recrystallized silicon since there are many annealing parameters to be seriously considered. In the experiment, we considered three dominant parameters, i.e., laser power, scan speed and substrate temperature. As the first consideration, we must know the maximum surface temperature in order to successfully recrystallize the polycrystalline silicon. The temperature is calculated by solving the heat flow equation. Lax showed that the maximum linear surface temperature at the laser beam center is given by [5].

$$Q_{max} = \frac{1}{2\sqrt{\pi}\,k(T)} \left[\frac{P(1\text{-}R)}{w}\right] \quad (1)$$

p' Laser power

R: Reflectivity of surface

W:Beam radius

K(T): Thermal conductivity of polycrystalliie silicon

The absorbed power per unit radius is

$$Pa = P\,(1\text{-}R)/W \quad (2)$$

Here, samples are covered by 500 Å - SiO2 layer, which was about 24% reflectivity [6]. The maximum surface temperature at athe beam center can be obtained as a function of the absorbed power per unit radius. In our case, for 38W laser power, Pa is 2220 W/cm and the maximum surface temperature is about 1200°C..

The second point to consider is the scan speed since the thickness of recrystallized silicon is determined by the scan speed which in turn is related to the effective dwell time for the scanning of a Gaussian beam. The effective dwell time is

$$t_{eff} = f \cdot \frac{2W}{V} \quad (3)$$

where f and V are the reduction factor and the scan speed respectively [7]. From the dwell reduction factor (f = 0.22) for room temperature substrate, the effective dwell time is about 13.3 msec.

The third point to consider is the substrate temperature. Since the substrate plays the role of a heat sink much more laser power is required to reach a given surface temperature if the substrate temperature is low. Therefore, in oder to obtain high quality recrystallised silicon, one must either raise the substrate temperature or lower scan speed. According to the Falster's results, cracks and ablation of recrystallized silicon was observed at a low substrate temperature [8].

We also note that depending on the CW CO_2 laser intensity, either liquid phase or solid phase regrowth of silicon should be achieved. The thickness of the recrystallized silicon in solid phase regrowth should be expressed [7] as

$$d = Ro.t_{eff}.\exp(-Ea/kTeff) \quad (4)$$

Ro: Constant which depends on the crystal orientation

t_{eff}: Effective dwell time

t_{eff}: Effective temperature which is equal to the maximum surface temperature

Ea: Activation energy

When we consider Teff as a function of laser power and substrate temperature, the recrystallized layer thickness can be calculated with the variation of the laser power at a fixed dwell time. From equation(4), we can predict that the recrystallized layer thickness at the laser power 38 W will be about 4100 Å.

III. Results and Discussion

Fig.4 is an SEM micrograph of polycrystalline silicon which is deposited by LPCVD. We observe from Fig.5 that the grain size is not apparently increased until laser power is 38 W. Fig.6 is an optical micrograph of the trace of laser beam line and local spots are melted

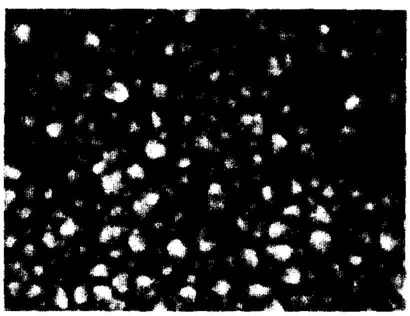

Fig. 4. Surface morphology of polycrystalline silicon before laser annealing (40.6KX).

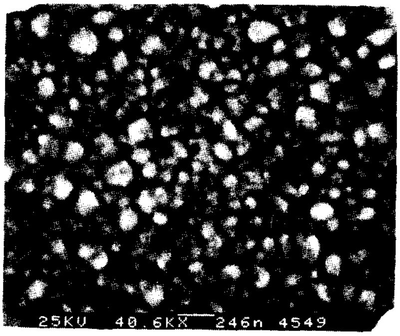

Fig. 5. Surface morphology at 38W laser power.

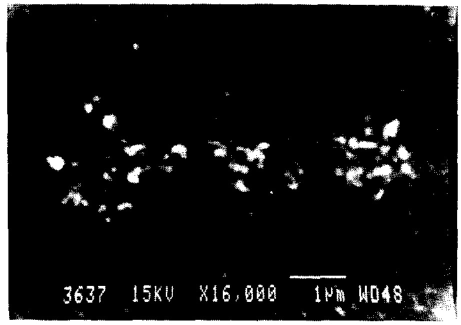

Fig. 7. Surface morphology by SEM micrograph at 39W laser power.

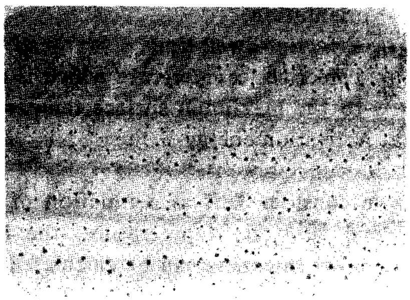

Fig. 6. Surface morphology by optical micrograph at 39W laser power (150X).

Fig. 8. Surface morphology at 41W laser power (300X).

zones. We observe that polycrystalline silicon is melted at the laser power of 39 W. These locally melted zones are known to be caused by the temperature profile created by the defference of thermal conductivity between the polycrystalline silicon and S_iO_2 [9,10,11]. If the polycrystalline silicon layer is deposited on a single crystalline substrate silicon without S_iO_2 buffer layer, the locally melted zones will not occur at 39 W laser power but larger melted zones will occur at a higher laser power than 39 W because there is no difference in thermal conductivity. Fig.7 shows the locally melted zone by SEM micrograph.

From Fig.7, we can conclude that polycrystalline silicon is in the liquid phase state when irradiated by 39 W laser power and the recrystallization is started during solidification process. Also, we can observe that the grain size is increased to the order of μm. Fig.8 shows that polycrystalline silicon is cracked when laser power is 41 W. This random microcracking is harmful for the utility of the recrytallized silicon. The microcracking is a consequence of the difference in thermal expansion coefficient between polycrystalline silicon and S_iO_2 layer, which produces tensile stress in the polycrystalline silicon film [12]. Stress relief grooves or formation of island structures before laser annealing are known to prevent this microcracking.

From the surface morphology, we conclude that polycrystalline silicon is in the solid phase state until 38 W laser power and becomes liquid phase state at 39 W laser power, but microcracking occurs at a higher laser power.

Resistivity and mobility of recrystallized silicon film are shown in Fig.9 as a function of incident laser power. For higher incident power, the resistivity of recrystallized silicon is reduced and the mobility is increased. As Gregory discussed, the large reduction of resistivity can not be ascribed solely to increased grain size [13]. Although the grain size is not increased for low laser power, it is observed the reduction of resistivity and the increase of mobility are significant. Since the resistivity of polycrystalline silicon is determined

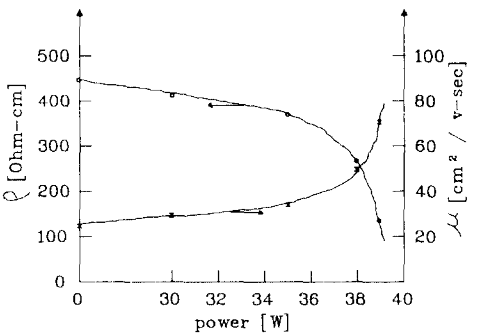

Fig. 9. The variation of resistivity and mobility with laser power.

by the grain size and trap density at grain boundaries under same doping concentration and temperature, we can conclude that this reduction of resistivity and increase of mobility are caused by the reduction of trap density at grain boundaries[14].

Therefore, our results give considerable support that the potential barrier created by the presence of carrier traps is reduced at the grain boundaries when incomplete bonds at grain boundaries is annealed by laser.

IV. Conclusion

In our study, the recrystallization of polycrystalline silicon film on S_iO_2 layer is performed by CW CO_2 laser. From the surface morphology, we observe that polycrystalline silicon is locally melted when it is irradiated at 39 W laser power and the grain size is increased to the order of μm. At a higher power than 41 W, the polycrystalline is cracked. Since these local melting and cracking phenomena are known to be caused by the difference of thermal conductivity and thermal expansion coefficient between polycrystalline silicon and S_iO_2 layer, we can propose that the seeded polycrystalline silicon or island structure will give a higher quality than our smaple structure.

From the Hall measurement, the reduction of resistivity and the increase of mobility are observed at a higher power. Therefore, we can confirm that the reduction of resistivity and the increase of mobility result not only from larger grain size but also from a larger reduction of potential barrier at grain boundaries. This observation is particularly interesting and useful for gaining further insights into the electrical conduction mechanism of recrystallized silicon.

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