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Annealing and Hydrogenation Effects on the Electrical Properties of Polysilicon Thin Films

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The electrical parameters of the microelectronic devices are limited by the presence of the grain boundaries, including dangling bonds, which can represent states with minority carrier traps. The improvement of photovoltaic efficiency requires a good understanding of the phenomenon of solidification, which varies with temperature. In this work, we study the influence of the annealing temperature and hydrogenation on the electrical conductivity and resistivity. The changes in resistivity as a function of heat treatments show that their overall contribution becomes important with increasing temperature before becoming dominant. The analysis by induced current shows the effect of recombinant grain boundaries and electrical activity.

Електричні параметри мікроелектронних пристроїв обмежені наявністю меж зерен, в тому числі обірваних зв'язків, які можуть представляти стани з пастками для неосновних носіїв заряду. Підвищення фотоелектричної ефективности вимагає хорошого розуміння явища тверднення, яке варіюється в залежності від температури. У даній роботі ми вивчаємо вплив температури відпалу і гідрування на електропровідність і питомий опір. Зміни питомого опору як функції термічних оброблень показують, що їхній загальний внесок стає важливим при підвищенні температури, перш ніж стати домінувальним. Аналіза за індукованим струмом показує ефект рекомбінантних меж зерен та електричної активности.

Key words: polysilicon, electrical conductivity, trap states, grain boundaries.

Ключові слова: полісилікон, електропровідність, стани пасток, межі зерен.

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1. INTRODUCTION

As a critical part of studies on silicon-based solar cell development, as widely reported recently, the techniques employed to characterize polysilicon have been improved drastically. The polysilicon material is used in many industrial applications such as microelectronic components [1–3], integrated circuits and photovoltaic generators [4, 5]. Circuit complexity and large-scale integration of these components require a constant upgrade to improve and control of the properties of these materials [6, 7]. During material preparation, polysilicon is subject to various heat treatments to reduce defects and allow implanted ions to take positions where they are electrically active. The diffusion of dopants is generally much higher in the grain boundaries than in grains [8, 9]. The importance of the average grain size in the polysilicon material depends on physical and electrical properties of this material. This has driven us in this work on the changes in electrical characteristics of polysilicon material, subjected to different heat treatments.

2. EXPERIMENTAL PART

Polycrystalline-silicon thin films were deposited by low-pressure chemical-vapour deposition (LPCVD) at 620°C by silane (SiH_4) decomposition. These processes are performed at a low (500 mTorr) pressure and deposition ratio 45 Å/min. The samples used in this work were the 0.688 μm thick polycrystalline silicon films deposited on single-crystalline silicon substrate of orientation <111> and resistivity from 6 to 12 Ω·cm [10]. To isolate the polysilicon thin film from the single-crystalline silicon substrate, a buffer layer of SiO_2 of 0.116 μm thickness was deposited on the silicon substrate. Deposited polysilicon thin films were irradiated with phosphor (P) and arsenic (As) ions at a dose of 10^{15} cm^{-2} and energy of 180 keV. Heat treatment was then applied to the samples for 120 min at a temperature varying from 1000°C to 1150°C before the ion implantation. The samples followed by another heat treatment after implantation at a temperature between 1050°C and 1200°C for 30 min. These heat treatments were followed by annealing at the end of the process at 450°C for 30 min under nitrogen or hydrogen. Measurements of the Hall effect and the resistivity were carried out on these films.

3. RESULTS AND DISCUSSION

Figures 1 and 2 show the reduction of the resistivity as a function of annealing temperature before and/or after ion implantation.

As the annealing temperature increases, the disordered atoms at the grain boundaries rearrange themselves and align along the preferred lattice sites, leading to the growth of the gain and, therefore, resulting in reduction of the density of the trap states and the sites

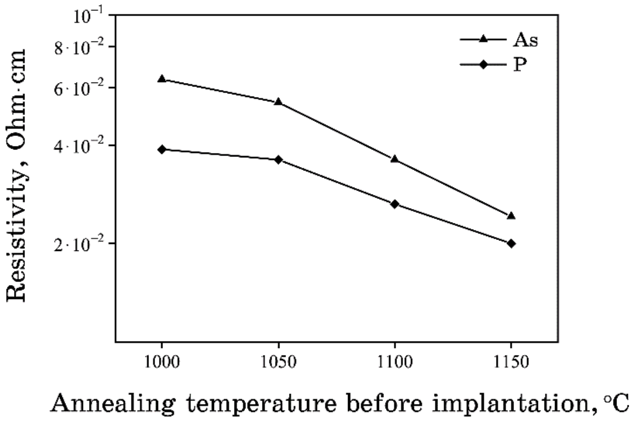

Fig. 1. Resistivity *vs.* the annealing temperature before implantation. These samples were annealed for a period of 120 min.

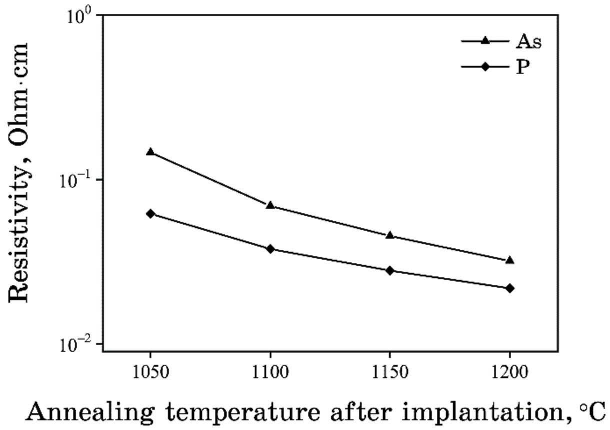

Fig. 2. Resistivity *vs.* the annealing temperature after implantation. These samples were annealed for a period of 30 min.

of segregation [11].

The reduction in the disorder and density of trap states implies and explains the reduction in resistivity as shown in Fig. 1. Results have been shown in scientific literature [12]. The decrease in the resistivity with the increase in the annealing temperature is due to the decrease in the density of defects, which are capable of diffusing carriers at the grain boundaries, when the samples are annealed at high temperature. These results in the decreased resistivity and, therefore, the enhanced mobility of charge carriers as reported by Mekhalfa *et al.* [13].

The strong reduction of resistivity in the samples doped with ar-

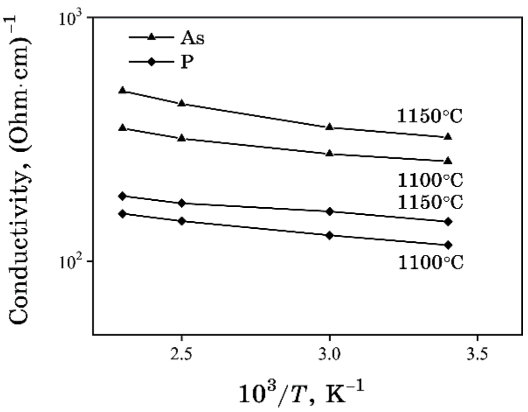

Fig. 3. Conductivity *vs.* the annealing temperature.

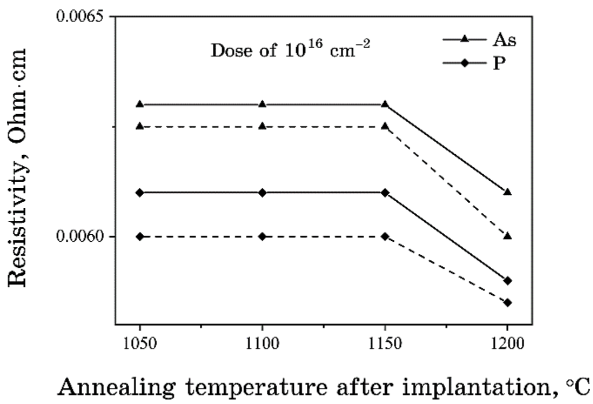

Fig. 4. Resistivity *vs.* the annealing temperature after implantation. The samples underwent annealing before implantation at 1150°C for 120 min. Dashed lines represent the curves of the samples, which were subjected to an annealing under hydrogen at the end of the process.

senic (As) implies a significant increase in the density of dopants, which interact inside the grains, when the temperature of annealing increases as compared to the case of the doping with phosphor as shown in Fig. 2. On the other hand, the diffusion of the arsenic atoms from the boundaries toward the inside of the grains is more important than that of the phosphor as shown in Fig. 2.

The variation of the conductivity as a function of annealing temperature is presented in Fig. 3. From Figure 3, it can be seen that the slope of the curve is negative, and it decreases when the annealing temperature increases. With the increase in temperature, the resistivity of the neutral regions increases [14] and excites the free carriers, which easily overcome the potential barriers with increased mobility and, thus, reduce the resistivity of regions of barriers. The change in the conductivity can also be attributed to the reduction of the density of the trap states and the segregation sites as a result of the rearrangement of the network of joints and the growth of the grains; this leads to increase in the free-carriers' concentration and reduction in the height of the potential barriers of deserted areas [15]. Concurrent to this, the I–V characteristics of the polysilicon samples with hydrogen passivation shows a systematic improvement that has been demonstrated in the literature [16–18].

Figure 4 shows that the resistivity of the polycrystalline samples annealed after implantation in the temperature range from 1050 to 1150°C remain unchanged and decreases sharply at 1200°C. These samples were subjected to an annealing under hydrogen at the end of the process. This indicates that, in temperature range between 1050 and 1150°C, the average grain size remains unaltered. The grain size increases thereafter at higher temperatures. We find that hydrogen reduces the resistivity and improves the mobility. Honda *et al.* [19] have shown that hydrogen passivation is essential for improving the properties of polycrystalline-silicon thin films.

4. CONCLUSION

The aim of this work is to study the effect of annealing temperature on the resistivity of the polysilicon thin films by activating and redistributing the implanted dopant atoms.

The polysilicon films doped by ion implantation with arsenic or phosphorus with an average dopant concentration of 10^{15} cm^{-3} were studied. The resistivity was negatively correlated with the annealing temperature before and/or after both P and As ion implantation. The resistivity dropped significantly for the samples with arsenic ion implantation. On the other hand, the resistivity is significantly higher in polysilicon films doped with arsenic than in phosphorus-doped films for the same dopant concentration.

The Hall mobility of phosphorus-doped polysilicon films was also found higher than that for films samples implanted with arsenic.

We found that hydrogen passivation is essential for improving the properties of polycrystalline-silicon thin films.

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