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Influence of doping and heat treatments on carriers mobility in polycrystalline silicon thin films for photovoltaic application

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Abstract

In this work, we investigate the influence of doping as well as heat treatments on the mobility of the carriers in polycrystalline silicon layers. It was found that any increase in both parameters leads to an increase in the mobility of the carriers. Such mobilities were shown to be higher in boron doped layers that those doped with arsenic. Moreover, for strong arsenic doping, after the initial increase, we observed a saturation region followed by a final decrease of carrier mobility.

Key Words: Solar photovoltaic cells, polycrystalline silicon, grain boundary, carrier mobility, doping, heat treatments

1. Introduction

It is well established that solar photovoltaic cells prepared from polycrystalline silicon, poly-Si, are greatly affected by the presence of the grain boundaries. These boundaries may form short circuits which would increase series resistance; they thus decrease the photovoltaic performances of the devices whose improvement and properties control are required [1–4]. In most of its applications, polycrystalline silicon is the subject of various heat treatments in order to reduce the defects and to allow the ions to be positioned in electrically active centers [5]. The improvement of the photovoltaic parameters goes through the reduction in the number of grains and consequently the reduction of the grain boundaries. This process could improve the photovoltaic output of the solar photovoltaic cells manufactured from this material. In this context, we investigate the variations of carrier mobility in polycrystalline silicon layers with boron as well as arsenic dopings at various heat treatments.

2. Experimental conditions

The investigation of doping and heat treatments on carrier mobility of poly-Si layers, as well Hall effect measurements and resistivity were carried out on 6880 Å thick samples deposited by LPCVD [6] on substrates

of single-crystal silicon of orientation <111> and resistivity 6 to 12 Ω·cm. An oxide film of thickness 1160 Å was use to isolate the layers from the substrate. Poly-Si layers were doped with boron (2.10^{14} to 10^{16} cm^{-2}) and arsenic (2.10^{14} to 5.10^{16} cm^{-2}) by ionic implantation. Heat treatments were carried out before and after implantation respectively at different temperatures ranging from 1000 to 1150 °C during 120 mn and from 1050 to 1200 °C for 30 mn.

3. Results and discussions

The various mechanisms which contribute to the limitation of carrier mobility in a layer of poly-Si are usually: (i) dispersion by the surface of the poly-Si layer, (ii) dispersion by the height of potential barriers of depleted regions, (iii) grain boundaries dispersion and (iv) ionized impurities dispersion. The surface free carrier dispersion gets significant when the mean free path of these carriers becomes comparable to the layer thickness [7]. However, in the case of our samples, the mean free path of the carriers ($\leq$ 27 Å) is much lower than the thickness of the layer, leading to a negligible limitation of carrier mobility.

Figure 1 shows the fast Initial increase in the carriers mobility in the low doping levels, such increase is explained by the strong reduction of potential barriers height of depleted regions. Indeed, in this range of doping, in spite of the increase in the average width of the grain boundaries and the concentration of the ionized atoms, the reduction of the potential barriers height of the depleted regions favors the increase of the carrier mobility.

When doping is increased, the potential barriers of the depleted regions decrease less quickly, whereas the average width of the grain boundaries and the concentration of the ionized atoms become more and more important. Thus, the mobility tends towards a maximal value then decreases as a result of the free carrier dispersion by the grain boundaries and the concentration of the ionized atoms. At very high doping, the limiting solubility slows down the increase in the concentration of the ionized atoms, and consequently it slows down the reduction of the mobility, especially for films treated thermally prior to implantation and arsenic doping; the excess atoms beyond solubility limit remain electrically inactive with apparently no influence on mobility [8]. On the other hand, one notes that the layers carriers mobility having undergone a long annealing treatment before implantation (1150 °C , 120 mn) or boron doping, is larger than that of original layers. This is mainly due to the (i) existence, in great quantity, of doping atoms and (ii) trapped carriers in grain boundaries in the case of an arsenic doping; and (iii) original layers prior to implantation.

Figures 2 and 3 show that the mobility increases when the annealing temperature increases (before and/or after implantation). This increase in mobility can be attributed to the atom rearrangements of the boundary network, to the growth of the grains and consequently, and to the reduction of the density of trapping states and segregation sites [9].

Moreover, the strong increase in the mobility of arsenic doped films shows, on the one hand, that there are much more atoms of doping agent which are found inside the grains when the annealing temperature prior to implantation increase, that in the case of boron doping, and on the other hand, that the diffusion of arsenic atoms of towards the boundary interior of the grains is more significant than that of boron. According to Figure 4, one notice that the carriers mobility remains constant for annealing, after implantation, lower than 1150 °C, and that it varies only for higher temperatures; thus indicating that the average size of the grains remains constant for temperatures of annealing lower than that of the heat treatment implantation, and that it increases for higher temperatures.

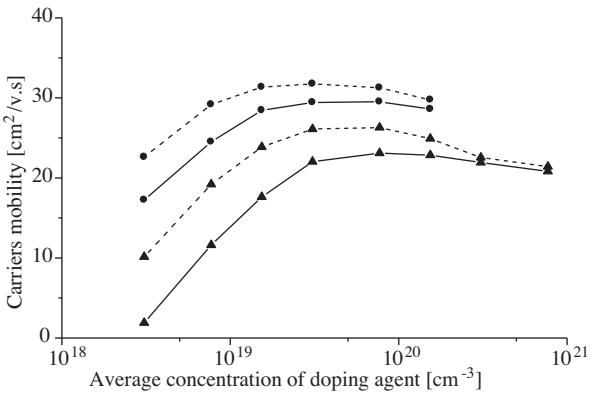

Figure 1. Carrier mobility as a function of doping concentration for arsenic (▲) and boron (●) doping obtained at an annealing temperature of 1100 °C for two different times 30 min (—-) and 120 min (−−).

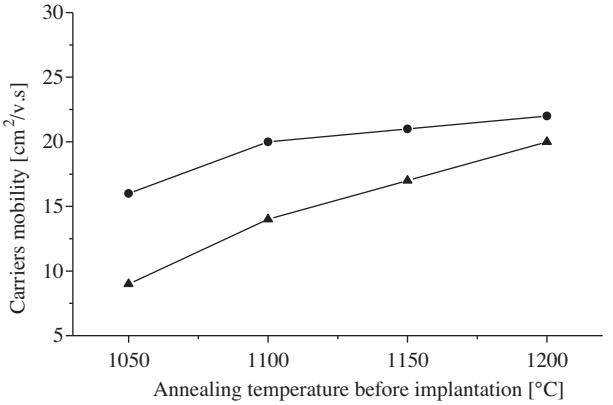

Figure 2. Carrier Mobility according to the temperature of annealing before implantation. These annealing were one duration of 120 min. All the samples underwent annealing after implantation with 1100 °C lasting 30 min. The triangles (▲) denote arsenic doping (10^{15} cm^{-2}) and the circles (●) denote boron doping (10^{15} cm^{-2}).

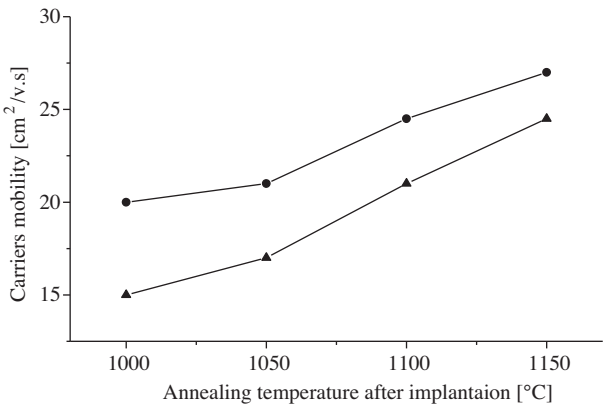

Figure 3. Carriers Mobility according to the temperature of annealing after implantation. These annealing were one duration of 30 mn. The triangles represent arsenic doping (10^{15} cm^{-2}) and the points boron doping (10^{15} cm^{-2}).

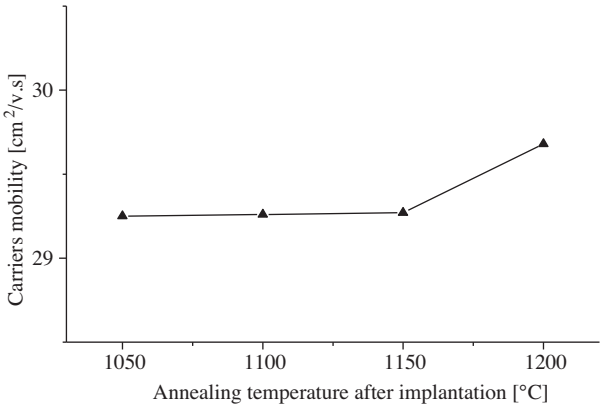

Figure 4. Carrier mobility according to the annealing temperature after implantation. Samples were annealed for 30 min. All samples underwent heat treatments before implantation at 1150 °C for 120 min, before to be doped with arsenic (10^{16} cm^{-2}).

4. Conclusion

The investigation of doping influence and heat treatments on the variations of the carrier mobility in layers of poly Si enabled us to deduce that the increase in doping levels as well as that of temperature in the heat treatments favors an increase in the carrier mobility. Thus, facilitating the flow of minority carriers through grain boundaries, and consequently, will improve the photovoltaic output of the solar cells prepared from this material. Moreover, it was noted that the carrier mobility in boron doped layers is higher than that in arsenic doped films. It was also noted that strong arsenic concentrations lead to a saturation followed by a reduction in carriers mobility.

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