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SOLID PHASE RECRYSTALLIZATION OF THIN POLYCRYSTALLINE SILICON FILMS IMPLANTED WITH Si^+ IONS

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Polycrystalline silicon films 300nm thick deposited by low pressure chemical vapour deposition at 650°*C* on oxidized silicon wafers have been implanted with 85 and 170 keV silicon ions at doses of $10^{14}, 10^{15}$ and 10^{16} ions/cm^2 at 7° from normal incidence and subsequently annealed at 1000, 1050, 1100 and 1195°*C*. This technique makes it possible to increase the grain size of thin polycrystalline films. The as-deposited film was {110} textured. For the highest doses the films lost their texture. The electron mobility of the poly-Si can be increased few orders in magnitude in this way. The most effective process was reached with the 85 keV energy, when more of the ions remained in the poly-Si layer (the projected range is equal to one half of the film thickness) as compared to the higher 170 keV energy when most of the ions reached the poly-Si film–SiO_2 interface.

1. Introduction

The development of a process that forms a device-quality silicon over insulators (SOI) has been the subject of active research in recent years. Reviews of the various approaches used to obtain SOI films and applications of the highest quality SOI's have already been published [1-7]. Among all the SOI technologies polycrystalline silicon thin film transistors (TFT's) have attracted particular attention in the field of large-area electronics, e.g. for liquid crystal displays. Grain size in polycrystalline silicon films on an amorphous insulating substrate may be enhanced by ion implantation and a subsequent annealing [8-10]. The process starts with deposition of polycrystalline silicon over SiO_2, then the film is implanted with silicon. A silicon ion beam amorphizes most of the polysilicon layer leaving intact a few properly oriented channelled grains. The surviving grains act as seeds for solid phase recrystallization, which takes place during a subsequent heat treatment.

Experiments indicate that the ion implantation is the source of both the grain size enhancement and the reorientation effects. Thereafter this process has been named seed selection through ion channelling (SSIC) [9].

In this paper the crystallization behaviour and electrical properties are examined in polycrystalline silicon films implanted with silicon ions to find their dependence on the dose and the annealing temperature.

2. Experimental

The polysilicon films used in the presented experiments were 300 nm thick deposited in a conventional low pressure chemical vapour deposition (LPCVD) equipment at approximately 650^oC on silicon wafers covered with 1 μm of thermally grown SiO_2. The implantation and annealing schedule used is reported in Table I. The samples were implanted with silicon ions with the ion beam tilted 7^o from the normal to the surfaces, the angle used in conventional implanter. All implantations were done at room temperature. Annealing of the implanted samples was carried out in the diffusion furnaces in a nitrogen ambient.

The recrystallization process was examined by X-ray diffraction and transmission electron microscopy (TEM). The X-ray analysis was carried out using a powder diffractometer in the conventional Bragg - Brentano set-up and the Cu $K\alpha$ radiation.

The integrated intensities have been measured in step regime using the standard $\theta - 2\theta$ scan. 5^o wide intervals (in 2θ scale) around the maxima have been scanned choosing constant step 0.02^o and constant counting time 10s. The background intensity has been approximated by a linear function.

The integrated intensity I_{hkl} for a powder sample is given as [11]

$$I_{hkl} = R_{hkl} A_c m_{hkl} |F_{hkl}|^2 \mathrm{Lp} e^{-2M}, \qquad (1)$$

where A_c is the transmission factor that in the case of a symmetrical Bragg reflection has the form [12]

$$A_c = (1/2\mu)[1 - \exp(-2\mu t/\sin\Theta)], \qquad (2)$$

where μ is the linear absorption coefficient, t the film thickness, m_{hkl} the multiplicity, F_{hkl} the structure factors. Further Lp, given as

$$\mathrm{Lp} = (1 + \cos^2 2\Theta)/[\sin\Theta \sin(2\Theta)] \qquad (3)$$

is the Lorentz-polarization factor and e^{-2M} is the Debye-Waller factor with

$$M = (B/\lambda^2)\sin^2\Theta, \qquad (4)$$

where B and λ are the Debye parameter and the wavelength of X-rays, respectively.

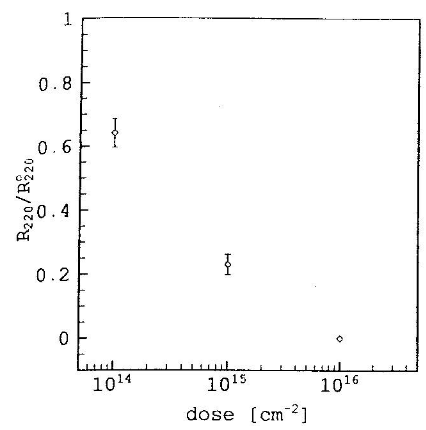


Fig.1: Ratios of the normalized intensities R_{220}/R^o_{220} as a function of implantation dose for the unannealed samples. The implantation energy was 170 keV. R^o_{220} corresponds to the as-deposited sample. The reflections (111) and (311) were undetectable for these samples.

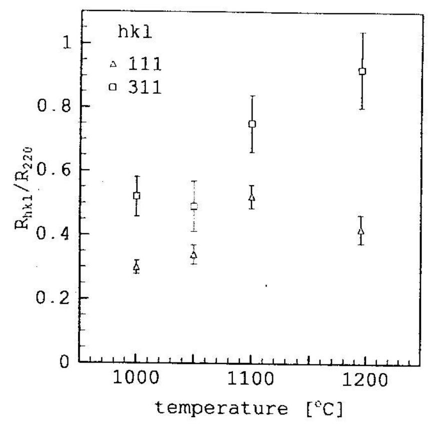


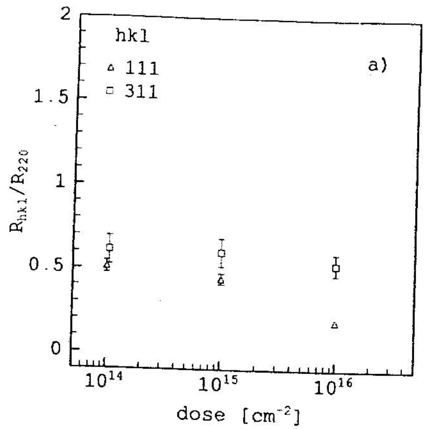
Fig.2: Ratios of the normalized intensities R_{111}/R_{220} and R_{311}/R_{220} as a function of annealing temperatures. The implantation energy, dose, and annealing time were 170 keV, 10^{15}cm^{-2},and 2 hours, respectively.

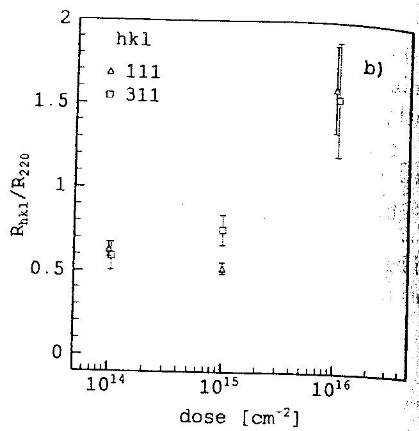
Table 1. Implantation and annealing schedule

		Annealing temperatures and times					
Energy	Dose	1100°		1000°	1050°	1195°	nonannealed
[KeV]	[cm^{-2}]	1h	2h	2h	2h	2h	
170	10^{14}	+	+				+
	10^{15}	+	+	+	+	+	+
	10^{16}	+	+				+
85	10^{14}		+				
	10^{15}		+				
	10^{16}		+				
unimplanted							+

The coefficient R, called hereafter as normalized intensity, is a constant for the given experimental set-up and is independent on the diffraction indices for an ideal polycrystalline sample. However, in the case of preferred grain orientation, R becomes a function of hkl and can serve as an indicator of the texture. Provided the primary and secondary extinctions do not take place, R_{hkl} is simply proportional to the number of grains having the planes $\{hkl\}$ parallel with the sample surface.

For TEM the specimens were prepared by backside ion-milling. Plane view bright-field observations were performed in the Philips CM-12 electron microscope at 120 kV. Further from the wafers the ribbons near the diagonal about 1 cm in width have





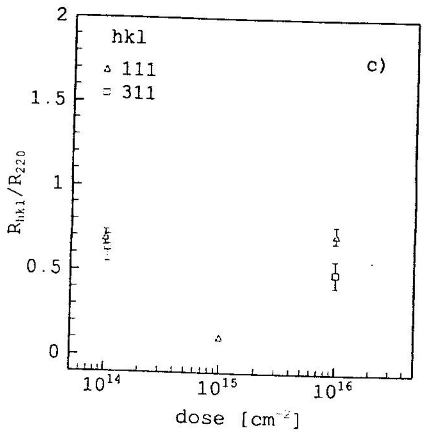
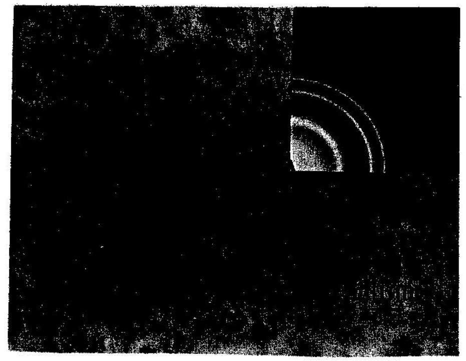


Fig.3: Ratios of the normalized intensities R_{111}/R_{220} and R_{311}/R_{220} versus implantation dose for various implantation energies and annealing times: a) 170 keV, 1 h; b) 170 keV, 2 h; c) 85 keV, 2 h. The annealing temperature was 1100°C. The missing mark at 10^{15}cm^{-2} in Fig.c) corresponding to the reflection (311) was undetectable.

been cut, which were then diced to squares approximately 1x1 cm^2 for the electrical measurements (7 pieces per wafer). The electrical resistivity, mobility and carrier concentration were determined using van der Pauw method. Hall measurements were done with a permanent magnet with B = 0.5 T. For samples with very small Hall constants the ac measurements have been applied.

3.Results

Normalized intensities R_{hkl} and their ratios have been evaluated for the three strongest diffraction lines of the crystallographic planes {111}, {220} and {311}. Calculations using the formula (1) have been performed with the appropriate parameters of



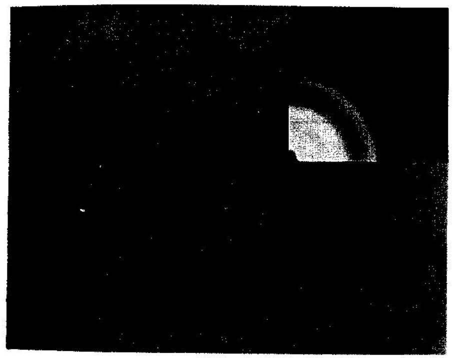


Fig.4: Plane-view bright field micrographs and diffraction patterns of the unannealed samples for various implantation doses: a) 10^{14}cm^{-2}; b) 10^{15} cm^{-2}; c) 10^{16} cm^{-2}. The implantation energy was 170 keV. The losing crystallinity with increasing doses is evident.

silicon and Cu Kα radiation [13,14]: $\mu = 1.41.10^4 m^{-1}$, B = 0.40.10$^{-2}nm^2$. The effect of anomalous dispersion and of the extinction have been neglected.

The results are shown in Fig. 1 to 3 where the ratios of the normalized intensities R_{hkl} are plotted against the annealing temperatures and the implanted doses. The measured intensities were in the most cases very weak due to the small thickness of the deposited poly-Si films. The largest error bars in the figures belong to the smallest diffraction peaks, because the error of measurement is inversely proportional to the square root of the total number of registered pulses.

The transmission electron micrographs and diffraction patterns of polysilicon films are shown in Fig. 4 and 5.

Experimental values of the resistivity and the mobility as functions of the annealing temperatures and the doses are shown in Fig. 6 to 8. All our samples showed the n-type

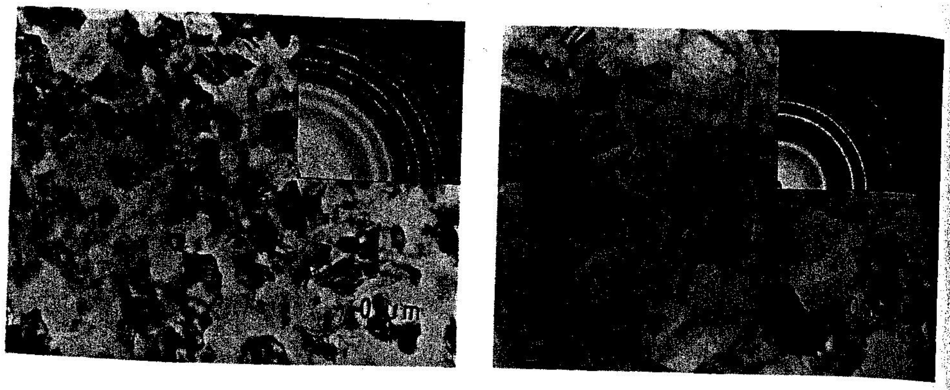


Fig.5: Plane-view bright field micrographs and diffraction patterns of the annealed samples. a) The implantation energy and dose were 170 keV and 10^{15}cm^{-2}, respectively. The samples were annealed at 1050°C for 2 hours. The grain sizes are practically the same as in the as-deposited samples. b) The implantation energy and dose were 85 keV and 10^{16}cm^{-2}, respectively. The samples were annealed at 1100°C for 2 hours. The increase of the grain sizes is evident.

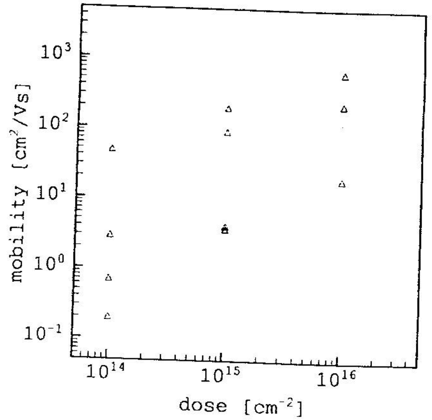


Fig.6: Electron mobility as a function of implantation doses. The implantation energy was 85 keV and the samples were annealed at 1100°C for 2 hours. The number of marks at the same dose equals the number of measured samples cut from the same substrate.

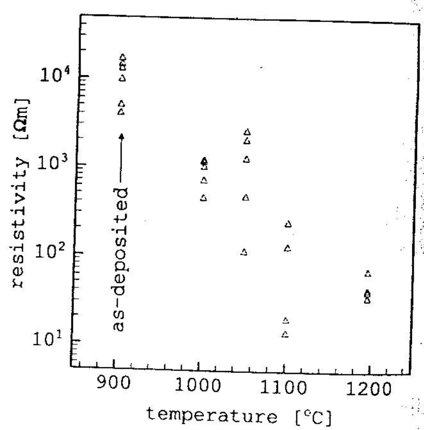
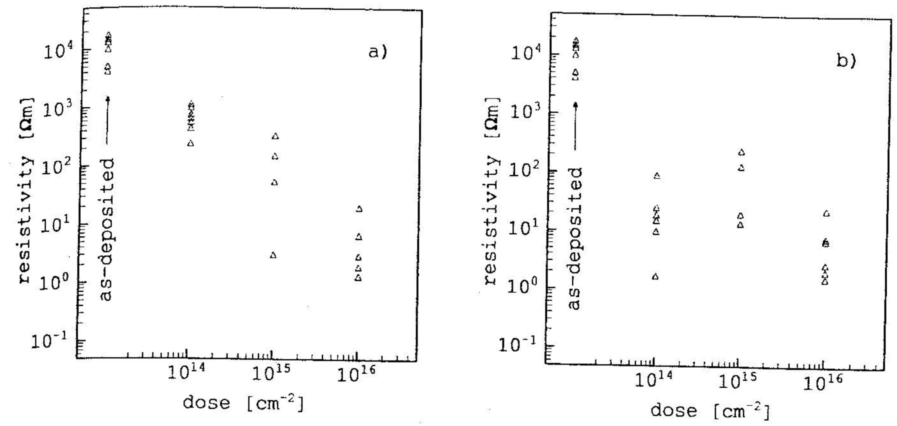


Fig.7: Resistivity versus annealing temperature. The implantation energy and dose were 170 keV and 10^{15}cm^{-2}, respectively. The annealing time was 2 hours. The number of marks at the same temperature equals the number of measured samples cut from the same substrate. The values for as-deposited samples are also shown.

conductivity. The average concentration of carriers was about 5.10^{14} cm^{-3}.



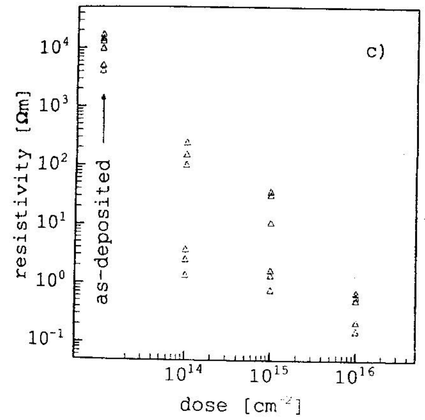


Fig.8: Resistivity as a function of implantation doses for various implantation energies and annealing times: a) 170 keV, 1 h; b) 170 keV, 2 h; c) 85 keV, 2 h. The annealing temperature was 1100°C. The number of marks at the same dose equals the number of measured samples cut from the same substrate. The values for as-deposited samples are also shown.

4. Discussion and conclusion

The as-grown undoped poly-Si layer showed the preferential orientation of the plane {110} parallel to the surface. Its high resistivity reflects the cleanness of the growth process. As one can see from Fig. 1 and 4 the grain sizes get smaller and the texture disappears with increasing dose of the implantation till the poly-Si film is amorphized at the dose 10^{16} ions /cm^2. According to [9] the implantation with such a high dose and the angle 7^o will give fully amorphized the poly-Si film, i.e. no crystalline grains will survive the implantation. If it is so, the recrystallization is not of the type SSIC. The largest grain sizes were observed for the dose 10^{16} ions /cm^2 and the energy of Si^+ ions 85 keV. At this energy most of the implanted ions are distributed at the center of the Si film, whereas for the energy 170 keV most of the ions reach the polysilicon film-

SiO_2 interface. For the case of 85 keV ion implantation the recrystallization mechanism seems to be of the type of strain-induced growth, in which the main driving force is the strain energy stored within the layer [8]. The lower doses were not sufficient to destroy the grown texture of poly-Si film and the implantation angle 7^o was not suitable for SSIC process to be the case.

From the electrical measurements it is seen that the resistivity decreases and the mobility increases with increasing dose. The highest measured mobility was 640 $cm^2V^{-1}s^{-1}$ for the implantation dose 10^{16} ions/cm^2, energy 85 keV and the 1100^oC 2 hours annealing. The increase of mobility is evidently correlated with the increase of the grain size.

The data, although from pieces of the same wafer, are probably dissimilar because of inhomogeneity across the wafer. A likely source is the high dose ion implantation (considered also in paper [10]) sustained by the high resistive SiO_2 underlay.

Although it is no evidence that the observed recrystallization is the SSIC process the results are encouraging. The mobility of the poly-Si can be increased few orders in magnitude using the silicon ion implantation into the silicon film on the insulating SiO_2. The most effective process was reached when the implanted ions remained in the poly-Si layer (the projected range equal one half the film thickness).

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