Zeitschrift: Helvetica Physica Acta

Band: 62 (1989)

Heft: 6-7

Artikel: Amorphous to single crystal transition in Si induced by ion-beam irradiation

Autor: Priolo, F. / Spinella, C. / Rimini, E.

DOI: https://doi.org/10.5169/seals-116072

Helvetica Physica Acta
Vol. 62 (1989)

0018-0238/89/070730-05$1.50+0.20/0

Amorphous to Single Crystal Transition in Si Induced by Ion-Beam Irradiation

F. Priolo, C. Spinella and E. Rimini

Dipartimento di Fisica, Corso Italia 57, I-95129 Catania (Italy)

G. Ferla

SGS-Thomson, Stradale Primosole 50, I-95100 Catania (Italy)

Abstract : The amorphous to single crystal transition in Si can occur at temperatures as low as 200^oC during ion-beam irradiation. The ion-assisted recrystallization of amorphous Si is here briefly reviewed. In particular the dependence of the process on the energy deposited by the impinging ions into elastic collision, on temperature and on impurities dissolved in the amorphous layer is presented and discussed.

1. Introduction

Amorphous Si ($a - Si$) has been the subject of considerable investigations during the last decade. At room temperature, $a - Si$, is metastable with the Gibbs free energy larger than that of crystalline Si ($c - Si$)[1], suggesting that a transformation to the stable crystalline phase will occur upon thermal heating. On single crystal substrates this transformation occurs by a planar motion of the $c - a$ interface. On $< 100 >$ oriented Si at 550^oC, the $c - a$ epitaxial regrowth rate is observed to be $\sim 1.3Å/sec$ which decreases to $\sim 0.05Å/sec$ at 475^oC[2]. This $c - a$ interface velocity is characterized by an Arrhenius expression with a single activation energy of $2.7eV$ over more than eight orders of magnitude[3].

The presence of impurities dissolved in $a - Si$ can strongly affect the regrowth. For istance dopants such as B, P and As increase the regrowth rate in a fashion depending on their concentration and species[4], whilst impurities such as C, O and F have the opposite effect and can eventually inhibit the motion of the $c - a$ interface[5].

Recently it has been shown that the epitaxial crystallization of amorphous Si layers can be obtained also at temperatures as low as 200^oC during ion-beam irradiation [6-8]. In this paper we will briefly review this process and in particular we will report the influence of dopants on the kinetics of ion-beam-induced epitaxial crystallization.

2. Experimental

Amorphous Si layers, $\sim 150nm$ thick, were produced by Si implantation at liquid nitrogen temperature onto $< 100 >$ Si substrates. Some of the preamorphized samples were subsequently implanted with $120keV$ As to a dose of $1 \times 10^{16}/cm^2$.

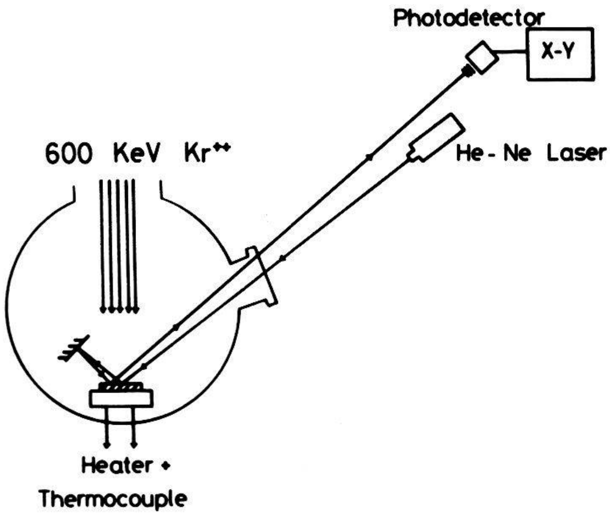
Crystallization was induced by irradiation with $600keV$ Kr^{++} beam at an ion flux of $1 \times 10^{12} ions/cm^2 sec$. The beam was electrostatically scanned over a sample area 2.5 cm in diameter. During the irradiations the samples were mounted on a resistively heated copper block whose temperature, monitored by a cromel-alumel thermocouple, was maintained constant in the range between 200 and 450^oC.

The ion-beam-induced regrowth was measured *in situ* during irradiation monitoring the reflectivity of a $He - Ne$ laser beam focused onto the irradiated area [9]. The experimental apparatus is schematically shown in Fig. 1. A small mirror placed near the sample reflects the laser light back to the wafer surface and then to the detector. The reflected light is detected by a photodiode connected to an $X - Y$ recorder whose X axis is driven by a signal proportional to the Kr^{++} dose. The reflectivity of the sample will oscillate due to constructive and destructive interferences occuring between the light reflected from the surface and from the advancing $c - a$ interface. In the adopted setup, the change in reflectivity from a peak to a contiguous valley corresponds to an advance of the $c - a$ interface of 33 nm.

3. Results and Discussion

In Fig. 2 (upper part) we report the reflectivity trace vs Kr irradiation dose for a $\sim$ 150 nm thick $a - Si$ layer simply produced by Si implantation and recrystallized at 350^oC by $600keV$ Kr ions. The oscillations in the reflectivity signal indicate the occurence of an interference between the light reflected from the surface with that reflected from the moving $c - a$ interface. Decreasing the distance from the surface, the amplitude of the oscillations increases due to a reduced absorption in the amorphous layer.

The lower curve reports the regrown thickness as a function of the Kr dose. After a dose of about $1 \times 10^{16} Kr/cm^2$ all the 150 nm *a*-layer is recrystallized. It should be noted that at the same temperature (350^oC) and during the time of the irradiation ($\sim$ 3 hrs)



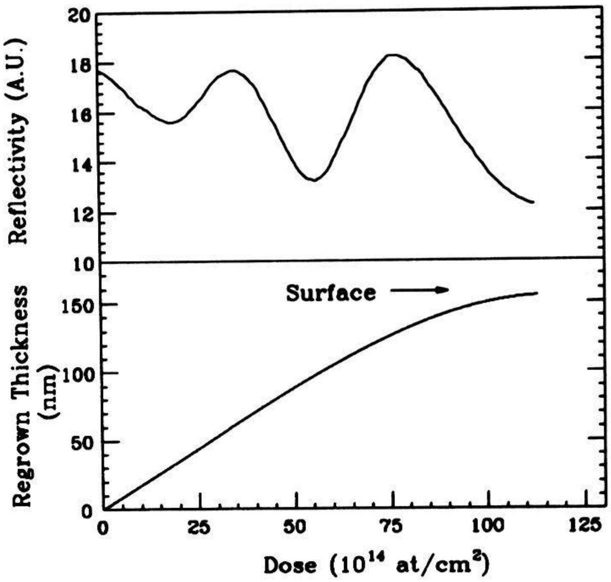


Fig.1.Experimental apparatus. Fig.2. Reflectivity trace during irradiation at 350^{0}C with 600 keV Kr ions (upper). The extracted regrown thickness vs Kr dose (lower).

the a-layer would have regrown thermally by just 6×10^{-3}nm.

The growth rate, i.e. the slope of the thickness vs. dose curve, shows a dependence on depth and this effect is related to a change in the number of atoms displaced into elastic collisions by the Kr ions at the moving $c - a$ interface. The number of displacements has been calculated by TRIM[10] program. The results, assuming a threshold energy for displacements of $13eV$ and a binding energy of $2eV$, are shown in Fig. 3 as open dots. The growth rate, as deduced from the transient reflectivity signal shown in Fig. 2, is also reported on the same plot as a continuous line. The experimental rates closely follow the calculated distribution of displacements. This result suggests that the ion-beam-enhanced growth is associated to the generation of point defects. No correlation has been found between the growth rate data and the energy deposited into electronic excitations.

Experiments similar to those so far reported were carried out varying the irradiation temperature. The experimental regrowth rates, normalized for the energy deposited into elastic collisions, have an Arrhenius-type temperature dependence with an activation energy of $0.32\pm0.05eV$, i.e. an order of magnitude lower than the pure thermal process ($2.7eV$). Further investigations are in progress to understand the actual meaning of this

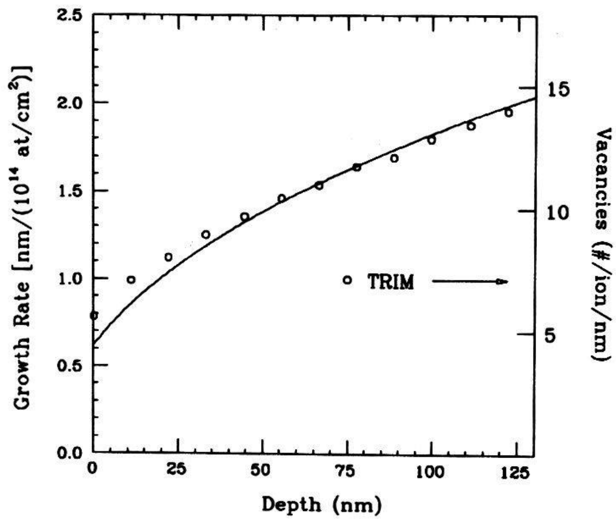


Fig. 3. Growth rate vs depth. In same figure, as empty dots, the number of vacancies generated by Kr beam and calculated by TRIM code is also reported.

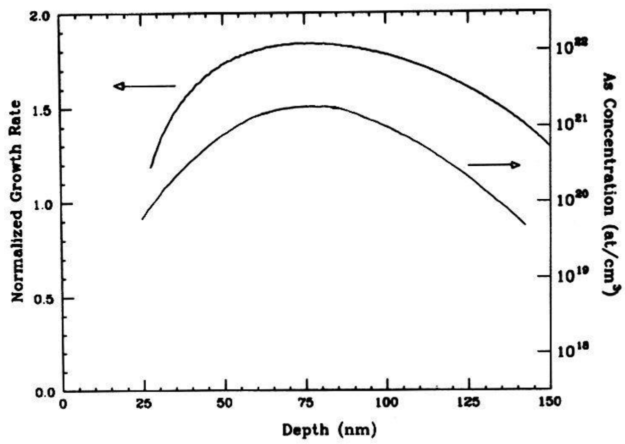


Fig.4. Normalized growth rate vs depth for an a-Si layer implanted with 120 keV As to a dose of $1 \times 10^{16}/cm^2$ and recrystallized at 350°C by 600 keV Kr ions. In the same the As profile is reported.

activation energy.

Impurities dissolved in the a-layer can influence the ion-induced motion of the $c - a$ interface. In the case of a variable impurity concentration dissolved in the a-layer the use of transient reflectivity is particularly powerful. In fact the reflectivity measurements directly yield the growth rate as a function of depth, dividing this datum to the rate of an impurity-free sample regrown under the same conditions one eliminates the depth dependence introduced by the energy lost by the impinging ions into elastic collisions (see Fig. 3), this normalized growth rate can then be directly associated to the impurity profile.

As an example in Fig. 4 is reported the normalized growth rate as a function of depth for an $a - Si$ layer implanted with $120 keV$ As to a dose of $1 \times 10^{16}/cm^2$ and recrystallized at 350 ^oC with $600 keV$ Kr ions. In the same figure is shown the As profile in a logarithmic scale. The normalized rate increases with increasing As concentration and it reaches a value of about 1.8 at a concentrantion of $\sim 10^{21}$ As/cm^3. The shape of the normalized rate vs. depth curve closely follows that of the As profile suggesting that the dependence of the rate on As concentration is logarithmic. Similar results have been found for B and P implanted in Si and B is more effective in the enhancement. A rate enhancement in presence of dopants is qualitatively in agreement with a similar effect observed during pure thermal annealing, the intensity of the effect is however rather different in the two cases. For ion-beam regrowth the enhancement is always within a factor of 2-3, whilst during pure thermal treatments it can exceed 2 orders of magnitude. An interpretation of these results is still under investigation. We however speculate that during irradiation an interaction between dopants and generated point defects increases their probability to remain in proximity of the $c - a$ interface and to interact with it.

References

[1] E.P. Donovan, F. Spaepen, D. Turnbull, J.M. Poate, and D.C. Jacobson, J. Appl. Phys. **57**, 1795 (1985)

[2] L. Csepregi, J.W. Mayer, and T. Sigmon, Phys. Lett. **A 54**, 157 (1975)

[3] G.L. Olson, S.A. Kokoroski, J.A. Roth, and C.D. Hess, Mater. Res. Soc. Symp. Proc. **13**, 141 (1983)

[4] L. Csepregi, E.F. Kennedy, T.J. Gallagher, J.W. Mayer, and T.W. Sigmon, J. Appl. Phys. **48**, 4234 (1977)

[5] E.F. Kennedy, L. Csepregi, J.W. Mayer, and T.W. Sigmon, J. Appl. Phys., **48**, 4241 (1977)

[6] J. Linnros, G. Holmen, and B. Svennson, Phys. Rev. **B 32**, 2270 (1985)

[7] J.S. Williams, R.G. Elliman, W.L. Brown, and T.E. Seidel, Phys. Rev. Lett. **55**, 1482 (1985)

[8] F. Priolo, A. La Ferla, and E. Rimini, J. Mater. Res. **3**, 1212 (1988)

[9] G.L. Olson, S.A. Kokoroski, R.A. McFarlane, and L.D. Hess, Appl. Phys. Lett. **37**, 1019 (1980)

[10] J. Biersack and L.G. Haggmark, Nucl. Instrum. Meth. **174**, 257 (1980)