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The Effects of Ions on the Formation of Polysilicon Films

A.Kawamura, J.Kudo, K.Iguchi, Y.Kubota, H.Sato, M.Koba and K.Awane

Central Research Laboratories, SHARP Corporation

2613-1 Ichinomoto,Tenri,Nara 632 Japan

The ionic effects on the formation of polysilicon films by Ionized Cluster Beam(ICB) were studied on two types of films. One of them was deposited at high temperature (Ts=480°C) in polycrystalline phase, while the other was deposited at low temperature (Ts=350°C) in amorphous phase and converted to polycrystal by subsequent annealing (550°C).

The accelerated ions influenced both films in their structures such as density of nuclei, preferential texture and surface morphology. The ionic effects were also confirmed by fabrication of n- and p-channel thin film transistors and CMOS ring oscillators.

1.Introduction

Polysilicon has been used as gates and load resistors in VLSI device technology . Formed on insulators,it makes an attractive material for thin film device applications, such as active matrix displays and stacked IC's.

In the active matrix application,in particular, it is significant to fabricate devices at low temperatures (<600°C), compatible with low cost glass substrates. Conventional LPCVD is usually used to form polysilicon films, but it requires substrate temperature above 600°C. Therefore it is difficult to use LPCVD for such low cost glass substrates. For this reason, high quality devices have not been reported in this temperature range, in part due to poor quality of polysilicon.

This paper shows that the Ionized Cluster Beam (ICB) method effectively improves the microscopic structure and electrical properties of low temperature polysilicon. It is noteworthy that the application of ion assisted technologies to the formation of thin films, including polysilicon, is currently attracting a considerable interest.[(1),(2)]

2.Experimental

Silicon films were deposited by ICB on <100> oriented silicon substrates covered with 400-nm thermally grown SiO_2. The schematic diagram of the deposition chamber and typical growth conditions are listed in Figure 1. Si clusters were ejected from a nozzle of a heated crucible and partially ionized and accelerated onto the substrate surface. The ion current densities were on the order of $\sim 10 \mu A/cm^2$,for ionized deposition. The films were formed either with or without ionization of depositing species, in order to comparatively investigate the ionic effects. To investigate the crystallinity of the ICB silicon films, TEM, SEM, RHEED and Raman scattering techniques were used. And thin film transistors were fabricated to evaluate their electrical properties.

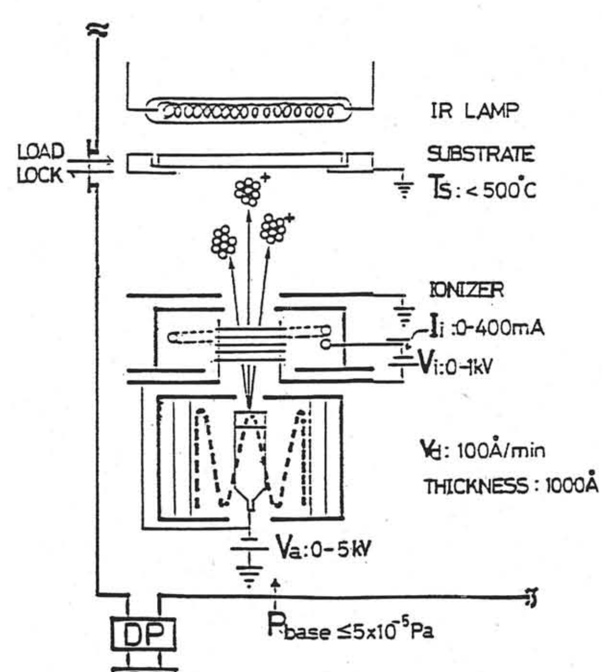

Fig.1 The ICB apparatus.

3.The effect of substrate temperatures

In the polycrystalline film formation, the substrate temperature is an important parameter which affects the generation and growth of crystalline grains. Therefore, prior to investigating the ionic effects, the temperature for the amorphous to polycrystalline transition was clarified first. Figure 2 shows the RHEED patterns of the films deposited without ion bombardment at low temperatures. It reveals that the film was amorphous at 375°C and polycrystallization started at 400-425°C,for the un-ionized deposition. Actually, the transition temperature did not significantly depend on the presence of ions in the deposition process. And this temperature was analogous to that of the Molecular Beam Deposition under UHV reported previously by other researchers.[3]

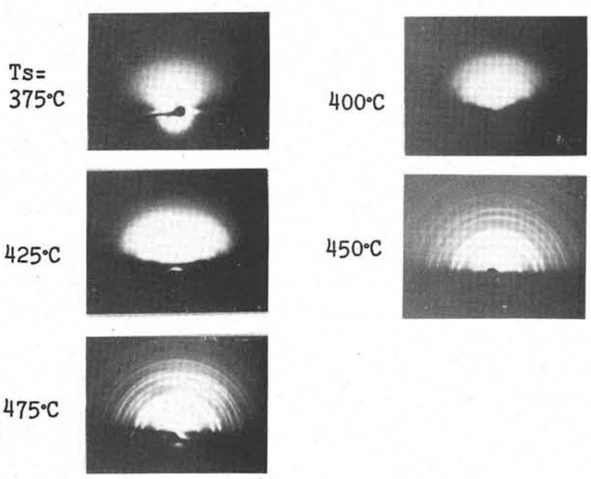

Fig.2 RHEED patterns of ICB Si films.

4.The ionic effects.

4.1 Low temperature films (Ts=350°C)

The films deposited at Ts=350°C were amorphous, irrespective of ion bombardment. However, these amorphous films could be recrystallized in subsequent solid phase grain growth, and the ionic effect became clear in recrystallized films.

The deposited films were annealed at 550°C for 30 to 70 hours in nitrogen to induce polycrystallization. Next these films were peeled off from substrates in dilute HF solution to form TEM samples. Figure 3 shows the bright field micrographs of recrystallized films, deposited with and without ion bombardment.

In the case of 30 hours annealing, dendritic grains were grown,but amorphous regions still remained between those grains. However these amorphous regions decreased with growth of dendritic grains. After 70 hours annealing, grains were impinged with other grains, and amorphous regions vanished.

Regardless of annealing time, the ionic effects were observed. Namely, the ion bombarded film had about an order smaller number of grains, compared to the unbombarded film. And the dendritic grains were grown to over 500nm in size in this film. Individual grains, generated in amorphous state, continue to grow until they impinge with other grains, and therefore, final grain size is expected to increase with decrease of number of generated grains[4]. The difference of grain number between ion bombarded film and unbombarded film may be explained as follows. During deposition, microscopic nuclei are created even at low temperature (Ts=350°C). Such nuclei grow into large dendritic grains in subsequent annealing. In case of the deposition with ion bombardment, film surface is irradiated with the accelerated ions. Microscopic nuclei may be attacked with them and part of them is destructed.

This fact indicates the possibility that the size and the number of grains in the subsequently recrystallized film could be controlled by the accelerated ions during film deposition.

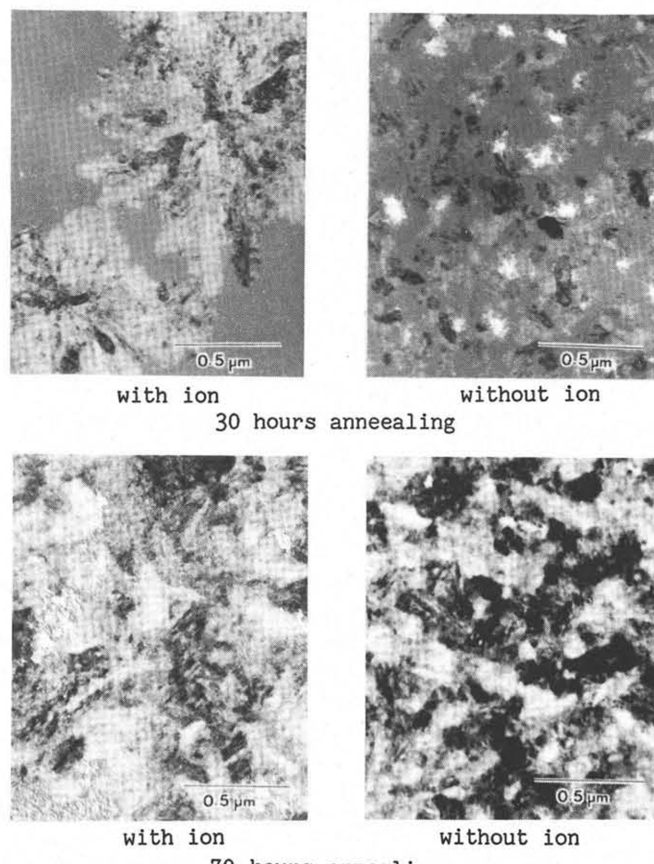

Fig.3 TEM photographs of Si films, deposited at 350°C with/without ion bombardment, and annealed at 550°C.

4.2 High temperature film (Ts=480°C)

As mentioned above, the films deposited at Ts=480°C, either with or without ions, were polycrystalline. And the average grain size of both films were almost same with each other as shown in Figure 4. In these films, the ionic effect on the density of grains that was noticed in low temperature films, was not observed. The reason may be that the grain density is a function of both the nucleation rate and destruction rate by ion bombardment. And at high deposition temperature, the nucleation rate would become much faster than the destruction rate.

However the ionic effects were clearly revealed in their crystallinity by TEM,RHEED and Raman scattering analyses.

As shown in Figure 4, the film formed without ions was composed of randomly oriented grains whose boundaries were quite loose. In contrast to this, the ion bombarded film had a mosaic structure with tightly connected grains. And it is particulary noteworthy that the texture, with the (420) orientation perpendicular to the surface, was induced in this film.

The Raman scattering analysis was applied to further investigate the film crystallinity. In Raman analysis, the spectrum of the single crystal silicon has a peak at 520cm^{-1} depicted with dash line in figure 5. The spectrum of the ion bombarded film is close to that of the single crystal silicon. This result also shows that the film crystallinity is enhanced by ions.

Another effect of ions was found in the surface morphology. To examine this, we used topographic SEM technique.[5] The ion bombarded film has a very smooth surface as shown in Figure 6.

All these ionic effects, i.e. preferred orientation, tightly connected grains and surface smoothness, would be expected to improve the polysilicon device characteristics. In the next section, we will mention the ionic effects on the polysilicon Thin Film Transistors (TFTs).

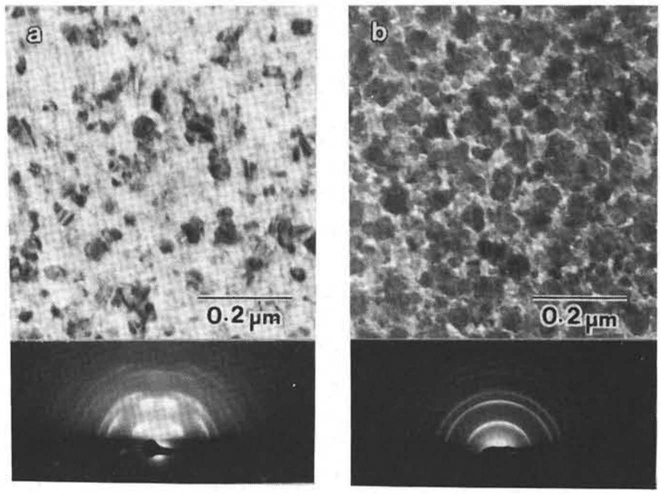

Fig.4 TEM and RHEED patterns of ICB polysilicon films deposited at 480°C (a) with ions, and (b) without ions.

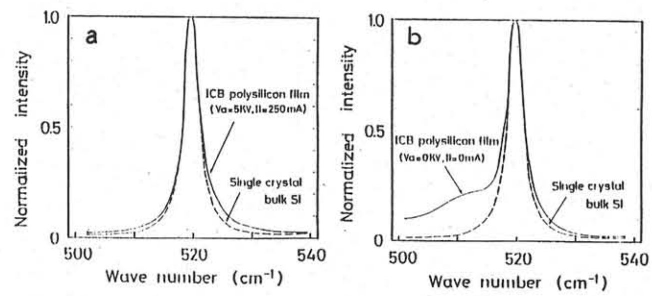

Fig.5 Raman spectra of ICB polysilicon films deposited at 480°C (a) with ions, (b) without ions.

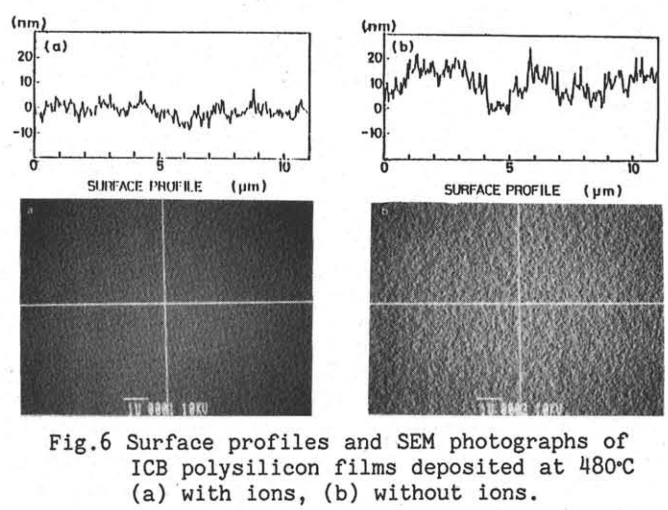

Fig.6 Surface profiles and SEM photographs of ICB polysilicon films deposited at 480°C (a) with ions, (b) without ions.

4.3 Thin Film Transistors

The improvment in film quality by ions was also confirmed by fabricating n- and p-channel thin film transistors. Polysilicon films were deposited on thermally oxidized silicon substrates at 480°C. After patterning these films, gate insulator was formed by conventional CVD at 420°C. Gate polysilicon was deposited by ICB, then P+ or B+ ions were implanted at source and drain regions utilizing the self-alignment technique. The impurities were activated by

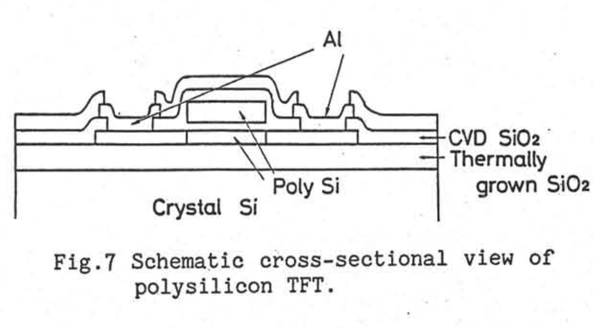

Fig.7 Schematic cross-sectional view of polysilicon TFT.

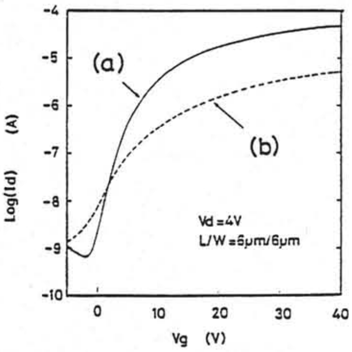

Fig.8 Log(Id)-Vg characteristics of n-channel TFT's. Polysilicon films were formed (a) with ions, (b) without ions.

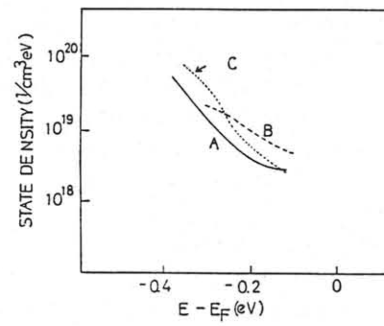

Fig.9 Trap densities of p-channel TFT's. Polysilicon films are A.ICB (with ions), B.ICB(without ions), C.LPCVD, respectively.

annealing at 550°C, and this temperature was the maximum in this process. After Al electrodes were formed, finally, hydrogen plasma annealing was done at 400°C to fill up the traps in the polysilicon with hydrogen atoms. The schematic cross-sectional view of this TFT was shown in Figure 7.

Figure 8 shows the log(Id)-Vg characteristics of the n-channel TFT. The ion bombarded film exhibited μ=11~12cm^2/Vsec, Vth=9~10V, Ion/Ioff=1$\times$10^5, Ioff<10^{-9}A. While, μ=0.5~1.1cm^2/Vsec, Vth=12~14V, Ion/Ioff=5$\times$10^3, Ioff>10^{-9}A were obtained from the film formd without ions.

The above result verifies that the device performance is sensitively influenced by the quality of polysilicon itself. In Figure 9, the densities of trap levels within the bandgap were compared for three polysilicon films, which were formed by (A) ICB with ions, (B)ICB without ions and (C) LPCVD, respectively. These curves were calculated from the chracteristics of P-channel devices. This clearly indicates the favorable effect of ions in reducing the trap levels in polysilicon, which eventually contributes to the enhanced mobility[6] and the reduced threshold voltage of the polysilicon devices.

Furthermore 19 and 31 stage CMOS ring oscillators were fabricated and their oscillations were observed. The typical waveform of 19 stage ring oscillator was shown in Figure 10. The delay time of 10.5 nsec/stage was obtained in the ion bombarded film.

5. Conclusions

The ionic effects on the low temperature (<600°C) formation of polysilicon films were studied in view of their crystallinity and electrical properties. The decreased density of nuclei at low temperatures and the enhanced textures at high temperatures were caused by the

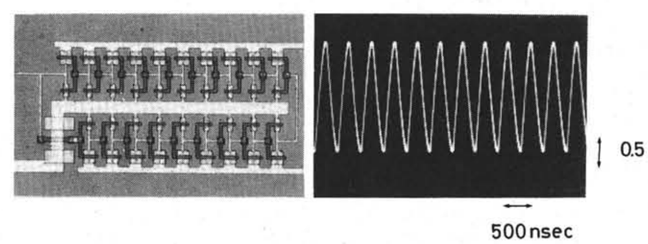

Fig.10 19 stage CMOS ring oscillator and its waveform.

accelerated ions. The ionic effects were also confirmed by fabrication of n- and p-channel thin film transistors.

The phenomena reported here are apparently caused by the interaction between microsopic grains and impinging ions. In addition to giving interesting information on these phenomena, the present approach seems to offer an effective means to form device quality polysilicon.

6. Acknowledgements

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7. Peferences

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