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ENHANCED CRYSTALLINITY OF LOW TEMPERATURE DEPOSITED SILICON FILMS ON GRAPHITE SUBSTRATES

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ABSTRACT

The previously developed technique for silicon crystallinity enhancement in silicon films deposited at low temperature is applied to graphite substrates. The measured increase in silicon crystallinity is comparable to that observed earlier using a quartz substrate. The distribution of aluminum in the silicon films is determined using Auger spectroscopic depth profiling. Carbon diffusion from the substrate into the silicon film is shown to be negligible at a substrate temperature of 600°C.

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In a previous paper we have shown a technique to enhance silicon crystallinity at low substrate temperatures for vacuum deposited silicon thin films.[1] An ultrathin Si-Al-Si (100Å-500Å-100Å) sandwich coating was used prior to silicon deposition. The silicon films thus deposited show a lower limit of 5μ for the silicon grain size. Optical microscopic measurement of the etched films further show that silicon grains as large as 200μ are produced.[2]

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In this work the same technique is applied to graphite substrates. Graphite is chosen because of its desirable properties as a substrate material for silicon thin film solar cells. Earlier work in which silicon films were deposited on graphite at high temperature showed significant diffusion of silicon and carbon into each other and the formation of silicon carbide.[3] Later work showed that, at a substrate temperature below 800°C, much less diffusion was observed.[2] Therefore, the Si-Al-Si sandwich coating technique should be applicable to the graphite substrate at 600°C to enhance silicon crystallinity without significant SiC formation. In addition, the difficulty encountered in our earlier study in determining the aluminum distribution is solved in the present work with an extra silicon coating as described later.

Silicon and aluminum were vacuum deposited onto graphite and quartz using conventional electron beam heating. The deposition rate was ca 40Å/min for both Si and Al. Other experimental parameters and Auger depth profiling measurement have been described elsewhere.[1,3] Commercial extruded graphite and fused quartz were used. Graphite substrates cut from a rod were used in both the unpolished and polished form. The latter was polished on Grit 320 SiC paper. Both graphite and quartz substrates were used in each deposition, the latter being used as a reference to be compared with the earlier work.[1] Substrates were outgassed at 800-900°C before deposition in a vacuum of 1×10^{-6} Torr.

An ultrathin Si-Al-Si (100Å-500Å-100Å) sandwich layer was first deposited onto the substrates which were held at room temperature. The substrates were then heated to 600°C and a thick silicon film of ca 2000-3000Å was deposited. Without further annealing the substrates were cooled down to room temperature and another layer of silicon (ca 300Å) was deposited. This last silicon coating is shown to be necessary to prevent the oxidation of aluminum, most of which stays near the surface of the film.[1] It also eliminates the presence of SiO_2 in the aluminum-rich region after exposing the film to air, since SiO_2 formation is restricted to a few monolayers. This technique allows reliable Auger determination of the aluminum distribution in the silicon film.

In this work we present the X-ray diffraction patterns of the silicon films deposited on graphite and quartz. In our earlier work[1] silicon films deposited on quartz showed a highly preferred (111) orientation with the 220/111 peak intensity ratio of ca 10-20%. Transmission electron micrograph of the same films showed spot diffraction pattern which implied a lower limit of 5μ for the silicon grain sizes. Since the same deposition technique is used in both studies,[4] the degree of silicon preferred orientation from the 220/111 intensity ratio is taken as a measure of the crystallinity enhancement over the pure silicon films deposited on quartz at 600°C. The latter showed both a powder-like X-ray diffraction pattern, with 220/111 being ca 60%, and diffused electron diffraction rings.[1]

Figure 1 shows the X-ray diffraction pattern for the silicon films deposited on graphite. Also shown is the X-ray diffraction of a Si film deposited on quartz which is obtained from the same experiment and is used as a reference. The 220/111 intensity ratio is ca 25% and 16% for the silicon films on graphite and quartz, respectively. Unpolished graphite was used in this case. Similar results were obtained using polished graphite substrates. These compare very well with the earlier work. Also seen in Fig. 1 is the (111) peak of aluminum which was not observed in our earlier work. This indicates the necessity of the described final silicon coating for the observation of aluminum. Auger depth profiles for the same films are shown in Fig. 2. Silicon film deposited on quartz shows a higher concentration of aluminum near the surface than in the bulk film. This confirms our earlier observation.[1] For the silicon film on graphite, the aluminum concentration stays nearly the same and is lower than that on quartz. Also observed is the diffusion of both aluminum and silicon into the graphite substrate. Quantitative determination of the aluminum distribution in graphite is difficult due to the scattering of data and an uncertainty in the sputtering rate of graphite.

The aluminum distributions described above are consistent with the observation that the aluminum (111) peak is more clearly seen in the silicon film on quartz than in the silicon film on graphite. Carbon diffusion from the graphite substrate into the silicon film is also shown to be negligible from Auger profiling, in agreement with earlier work.[2] In several cases silicon deposition was made with a different Si-Al-Si sandwich coating. Using a Si-Al-Si (100Å-200Å-100Å) sandwich coating, the silicon 220/111 intensity ratio was found to be similar to that using the Si-Al-Si (100Å-500Å-100Å) coating.

In summary, our results indicate that, using graphite substrates, an enhancement in silicon crystallinity can be obtained which is comparable to that using quartz substrates. Carbon diffusion into the silicon film is shown to be negligible at a substrate temperature of 600°C. Silicon diffusion into the graphite substrate is also low compared with that at 1200°C substrate temperature.[3] Furthermore, graphite in the unpolished form gives enhancement in silicon crystallinity similar to that on polished graphite. This may prove to be a further favorable economic factor in using graphite as a substrate material for silicon thin film solar cells.

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REFERENCES

1. C.-A. Chang, W. J. Siekhaus, T. Kaminska and D. T. Huo, Appl. Phys. Lett. 26, 178 (1975).
2. C.-A. Chang, unpublished results.
3. C.-A. Chang and W. J. Siekhaus, J. Appl. Phys, in press.
4. This implies that the same mechanism of silicon crystallization from the Si-Al eutectic melt should be involved in both studies.

FIGURE CAPTIONS

Fig. 1. X-ray diffraction patterns for the silicon films deposited on (a) graphite, and (b) quartz, using the Si-Al-Si sandwich coating technique.

Fig. 2. Auger depth profiles for the silicon films deposited on (a) graphite (a) graphite, and (b) quartz, using the Si-Al-Si sandwich coating technique. Sputtering rate of the silicon films is ca 50Å/min for (a) and ca 30Å/min for (b).

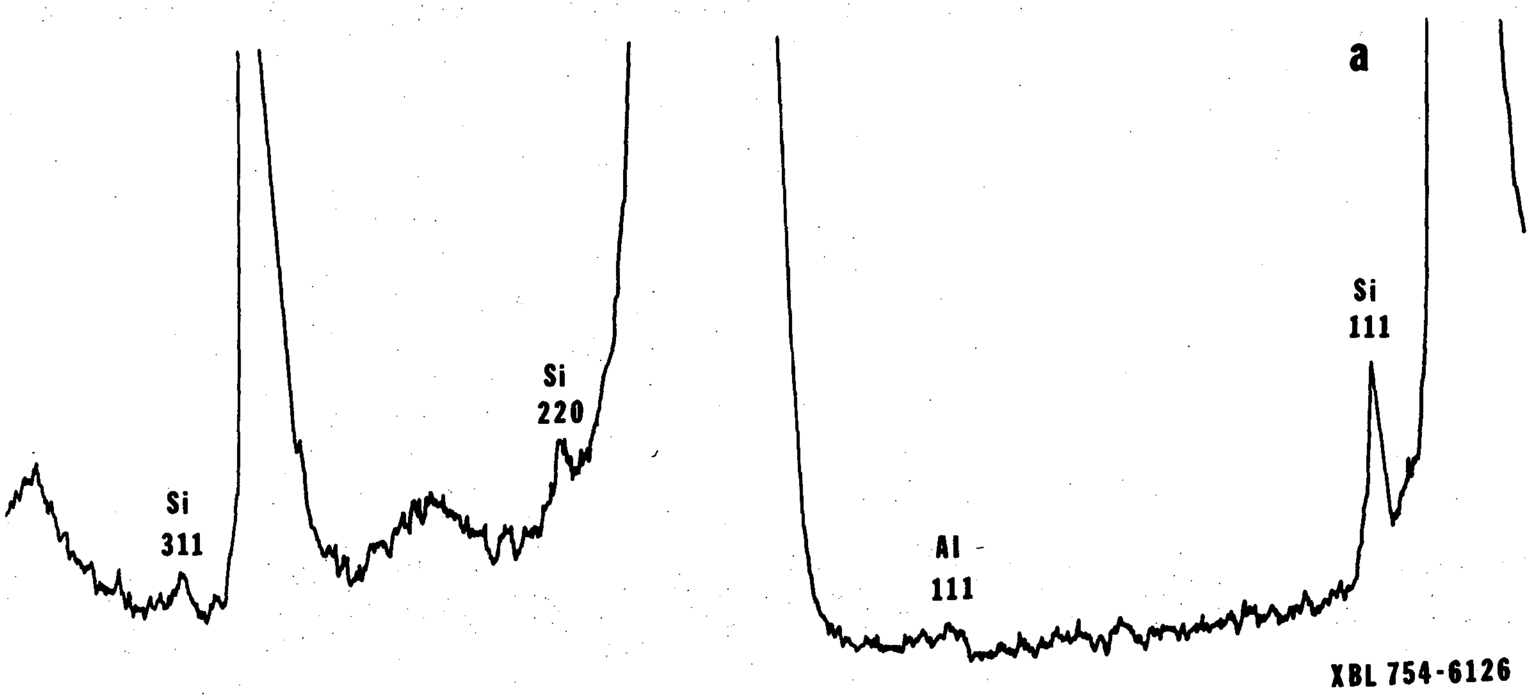

Fig. 1

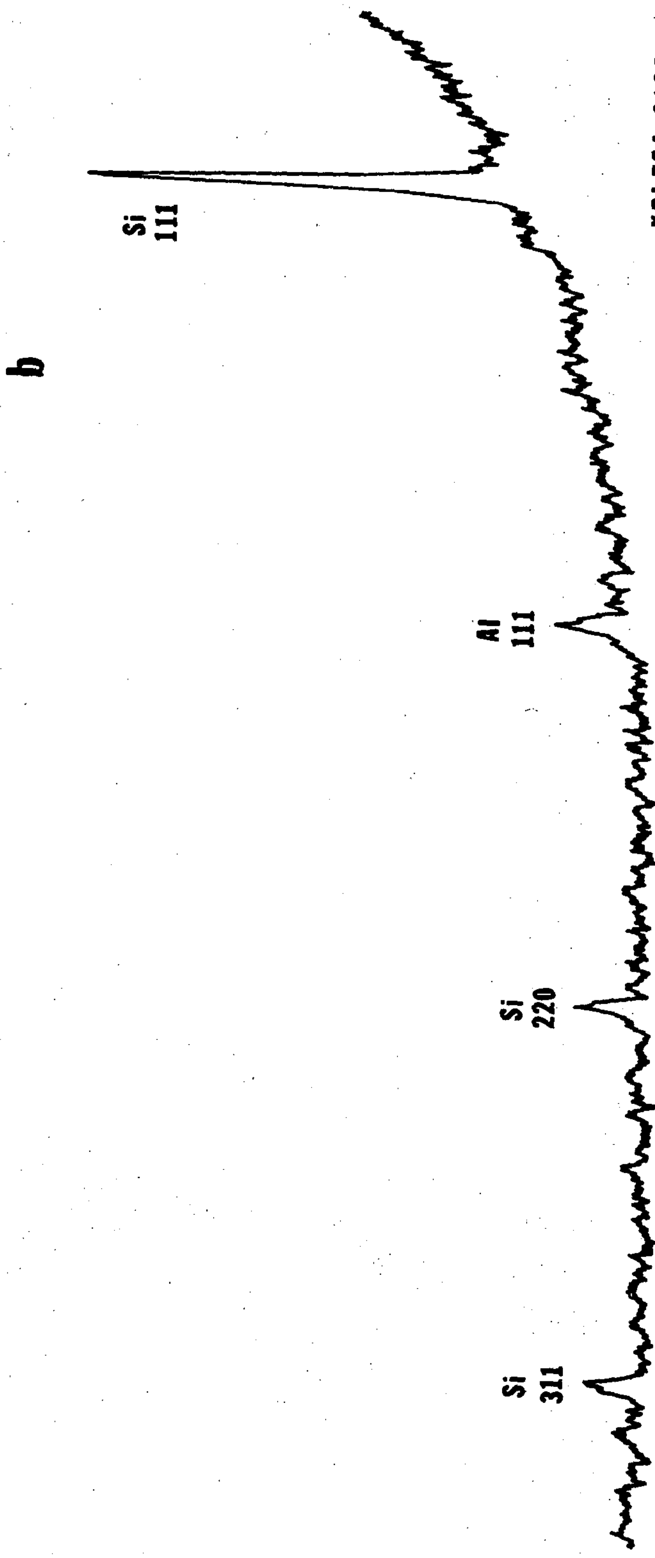

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Fig. 1 cont.

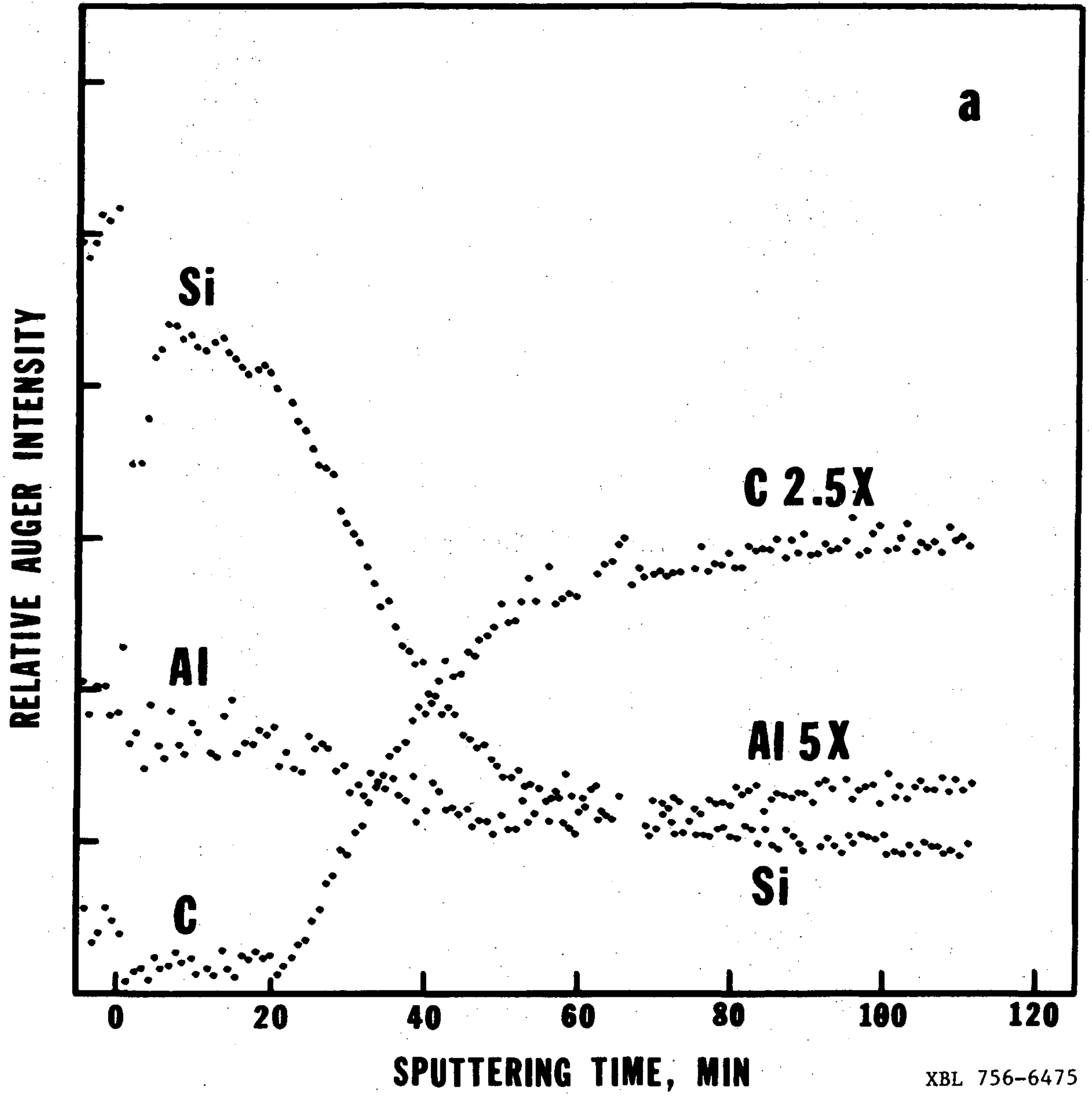

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Fig. 2

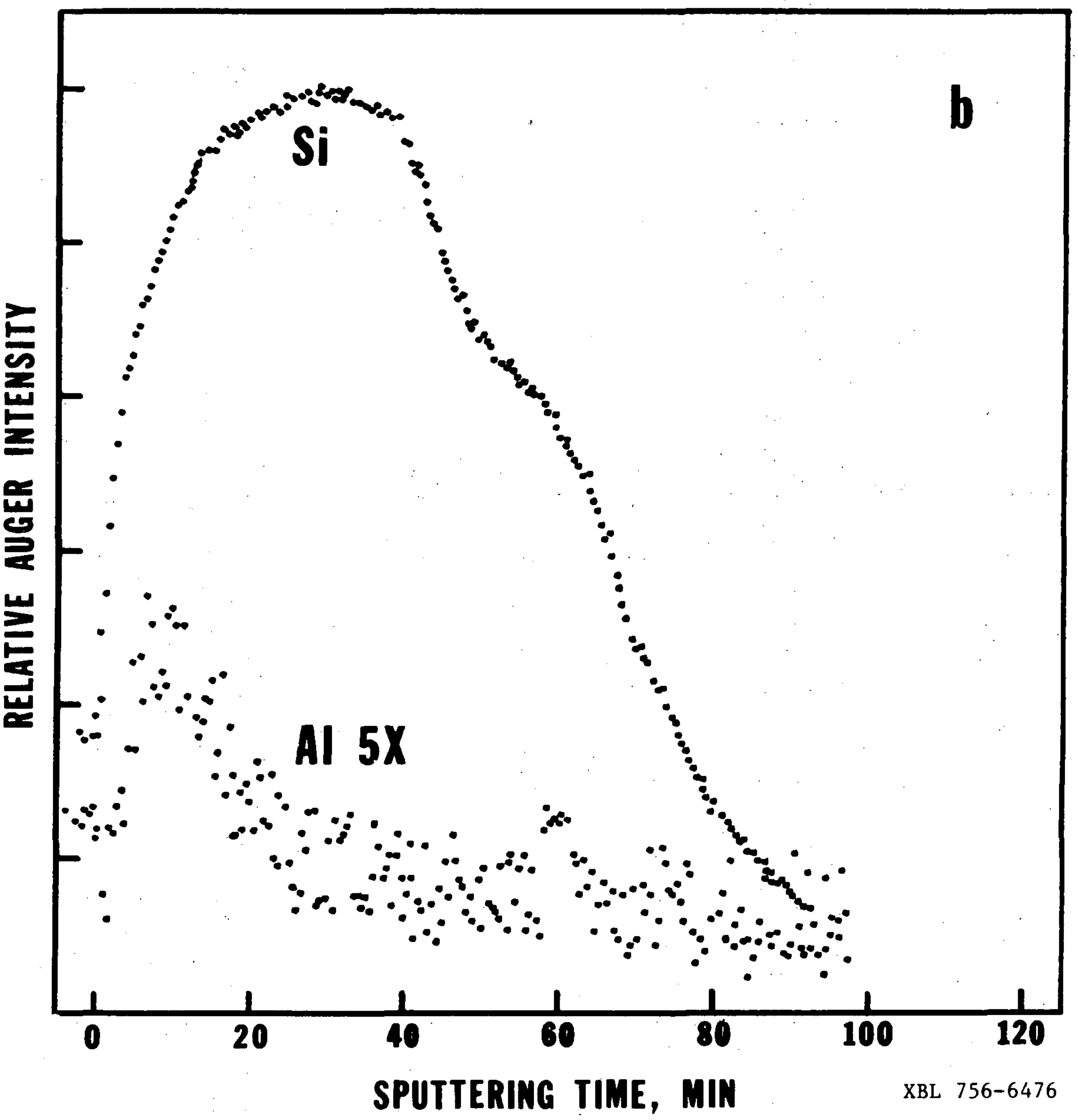

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Fig. 2 cont.

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