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Strain-relief spiral buckling of a-Si : H films

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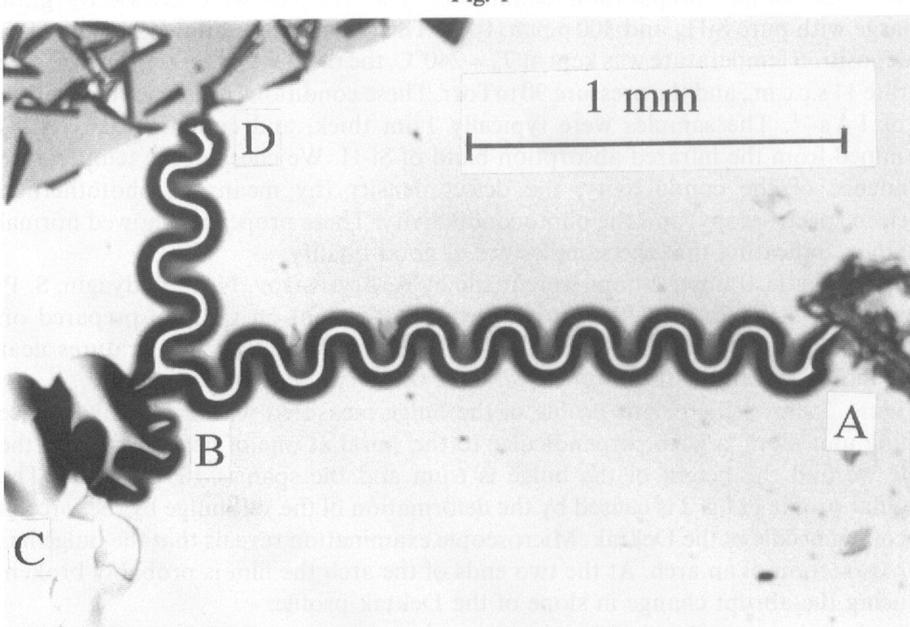
ABSTRACT

We have observed a spiral-shaped buckling of phosphorus-doped hydrogenated amorphous silicon(a-Si : H) films deposited on glass and on crystalline Si substrates. The spiral pattern has a wavelength of 0·02 cm and develops at a speed of about 0·01 cm min^{-1}. The buckling effect can be initiated by mechanical perturbation. The cross-section of the bulge is an arch with a height of 4·5–6 μm and a span of 100 μm. This kind of buckling is observed in 1 μm thick films having internal compressional stress exceeding about 6×10^9 dyne cm^{-2}.

We have observed a spiral buckling effect in hydrogenated amorphous silicon(s-Si : H) thin films. Figure 1 is a microscope picture of the buckling in a film grown on a Corning 7059 glass substrate. This pattern was first initiated by a scratch with a razor blade. The spiral grew out from an edge of the scratch (position A) with a speed about 0·01–0·03 cm min^{-1} to position B and then proceeded to C. The section between B and C collapsed like a bubble popping away, before the spiral continued to grow with the same speed from B to D until it came to a stop at a previously deposited metal electrode. The pattern of the buckle is nearly sinusoidal, with a wavelength of 0·02 cm.

Fig. 1



Photograph of the spiral buckling effect on a 300 p.p.m. P-doped a-Si : H film.

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The same kind of buckling effect has been observed in several samples. Some pieces were made at the same time as the sample shown in fig. 1. Another is a 3 p.p.m. P-doped a-Si : H films prepared above $T_d = 200°C$ is usually compressive. Its magnitude was samples have less than three periods but with about the same wavelength. We do not understand why the films buckle in such a spiral shape. Buckling presumably occurs when the force per unit area exerted by the film at the interface exceeds the interface adhesion force. The former is the product of film thickness and internal stress in the film while the latter are governed by the chemistry and cleanliness of the substrate. It is therefore difficult to specify the conditions which yield buckling. The internal stress in a-Si : H films prepared above $T_d = 200°C$ is usually compressive. Its magnitude was found to increase from 10^9 to 8×10^9 dyne cm^{-2} with increasing argon dilution of the reactant SiH_4 gas from zero to 95% argon for a $T_d = 250°C$ deposition temperature (Harbison 1984). The d.c. self-bias voltage during growth affects the magnitude of the internal stress. We found that films deposited at $T_d = 250°C$ on the plate biased -80 V with respect to the plasma (cathode plate) have twice the stress observed in films grown on the anode plate. Spear and Heintze (1986) reported tensile stress in films deposited below 150°C and increasing compressive stress for temperatures 150 and 300°C with a maximum value of 8×10^9 dyne cm^{-2} at $T_d = 300°C$. Doping tends to decrease the internal stress.

We observed the buckling pattern shown in fig. 1 in a 1 μm thick film deposited at $T_d = 240°C$ on Corning 7059 glass after the sample had experienced many quenching and annealing cycles between 200°C and room temperature. Moreover, no buckling or peeling was observed prior to scratching the film with a razor blade. The internal compressional stress was about 6×10^9 dyne cm^{-2}. Films having somewhat less stress were made to buckle after scratching by bending the substrate and thereby increasing the stress by $1{\cdot}3 \times 10^9$ dyne cm^{-2}.

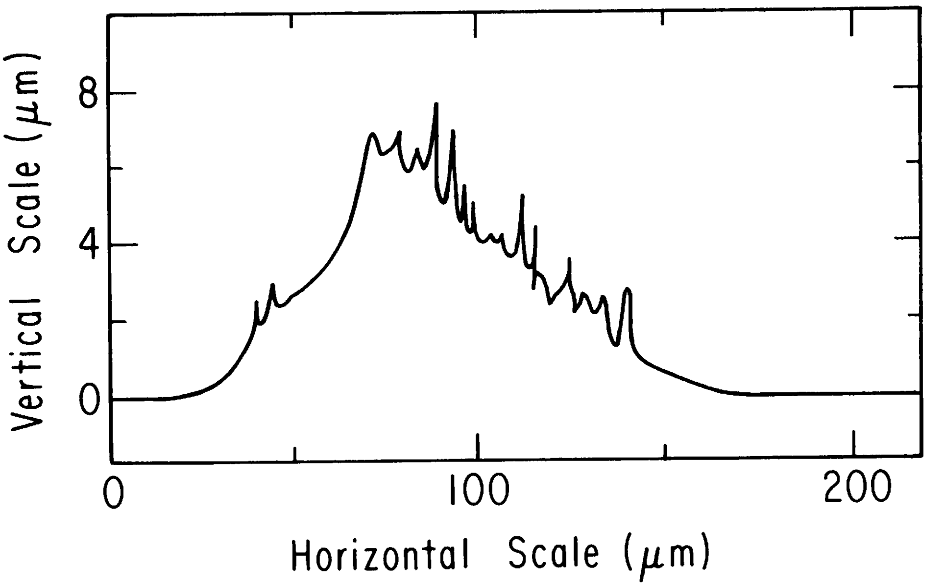
Not knowing which other parameters may affect these observations, we briefly mention our sample preparation conditions. The samples were grown by glow discharge with pure SiH_4 and 300 p.p.m. PH_3. The phosphine is diluted in He to 1%. The deposition temperature was kept at $T_d = 240°C$, the r.f. power was 0·25 W cm^{-2}, the flow rate 11 s.c.c.m., and the pressure 90 mTorr. These conditions produce a deposition rate of 1 Å s^{-1}. The samples were typically 1 μm thick, and contain 8 at.% H, as determined from the infrared absorption band of Si-H. We checked the temperature dependence of the conductivity, the defect density (by means of photothermal deflection spectroscopy) and the photoconductivity. These properties showed normal behaviour, indicating that the samples are of good quality.

Nearly identical observations were made by A. A. Aivazov, N. V. Bodyagin, S. P. Vikhrov and S. V. Petrov (1989, private communication) on samples prepared on crystalline Si wafers with 10% SiH_4 and 90% H_2, at deposition temperatures near 100°C and lower, and with power densities of 0·1 W cm^{-2} at 50 Pa pressure.

Figure 2 shows the height profile of the bulge measured with a Dektak surface profiling unit along a path perpendicular to the spiral at one of its kinks. From the profile we find the height of the bulge is 6 μm and the span is 100 μm wide. The triangular profile in fig. 2 is caused by the deformation of the soft bulge by the force of the probing needle of the Dektak. Microscopic examination reveals that the bulge has the cross-section of an arch. At the two ends of the arch the film is probably broken, producing the abrupt change in slope of the Dektak profile.

The bulges can collapse either by themselves or by external force. The height profile measured after a bulge had collapsed is shown in fig. 3 (*a*). Figure 3 (*b*) is a sketch

Fig. 2

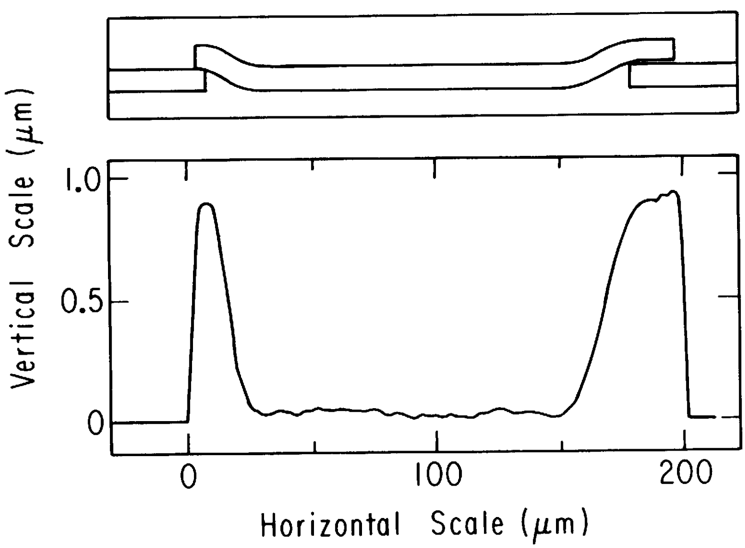


The height profile of the bugle measured with a Dektak surface profiler.

Fig. 3

(*a*)

(*b*)



(*a*) The height profile after the bulge had collapsed. (*b*) Probable picture of the cross-section of the bulge after collapsing.

of the piece of film which would yield the observed profile according to our understanding. Figure 3 suggests that the bulge usually breaks at the edges and not at the centre. The excess parts, due to expansion after compressive stress was relieved, overlap the undisturbed film causing the two bumps in fig. 3.

If we attribute the buckling effect to the intrinsic stress in the sample, we can calculate the stress from profiles such as that shown in fig. 2. The height of different bulges ranges from 4·5 to 6 μm. The span is 100 μm. So the relative expansion is $\Delta l/l = 0{\cdot}004$–$0{\cdot}007$. From the value of Young's modulus of a-Si : H, namely $1{\cdot}5 \times 10^{12}$ dyne cm^{-2} (Jansen, Machonkin, Palmieri and Kuhman 1987, Grimsditch, Senn, Winterling and Brodsky 1978), we calculate a compressional stress of 6–10×10^{9} dyne cm^{-2}, which is expectedly a little higher than published values (Harbison, Williams and Lang 1984, Spear and Heintze 1986, Ghaith 1987, Kakinuma, Nishikawa, Watanabe and Nihei 1986).

In conclusion, spiral buckling has been found in a-Si : H films grown on glass substrates and on crystalline silicon substrates. The buckling pattern is spiral with a wavelength of about 0·02 cm, a width of 0·01 cm, and propagates with a speed of 0·01–0·03 cm min^{-1}. The bulges are soft and bubble-like. The cross-section of the bulge is 4·5–6 μm high and 100 μm wide. The bulges break at the ends of the arch. The buckling effect may be caused by the intrinsic compressional stress in the material which we estimated to be 6–10×10^{9} dyne cm^{-2}. The mechanism yielded a spiral pattern is not understood.

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