

# Dependence of electrical conductance of a-Si:H films on Na concentration in glass substrate

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*The electrical conductance of a-Si:H is studied in films deposited on ion-exchanged optical waveguides in glass substrates. The effect of chemical composition of the near-surface region of the waveguide is considered from the viewpoint of the electrical instability of a-Si:H related with the penetration of Na ions from the substrate into the film. The optical waveguides have been prepared by Ag<sup>+</sup>-Na<sup>+</sup> or K<sup>+</sup>-Na<sup>+</sup> thermal or field-assisted ion exchange in soda-lime glass (SLG). The Na concentration in the near-surface region of the glass substrate has been established by means of elastic recoil detection analysis (ERDA). The obtained results demonstrate the possibility of reduction of electrical instability of a-Si:H films deposited on optical waveguides in glass. It is shown that in some cases an additional Na depletion of the near-surface region is necessary to avoid Na contamination of the a-Si:H films.*

**Keywords:** hydrogenated amorphous silicon, electrical instability, optical waveguides, ion-exchange in glass.

## 1. Introduction

Nowadays hydrogenated amorphous silicon (a-Si:H) films are widely used for the photovoltaic applications due to their high photosensitivity in the visible spectral range. It has also been shown that a-Si:H-based devices are suitable for application in integrated optics [1–3]. The low-temperature process used for a-Si:H deposition, such as plasma-enhanced chemical vapour deposition (PECVD) makes this material especially attractive for the integration with optical waveguide structures [1]. In the case of waveguides prepared in glass the Na-containing substrates are used, which could cause Na contamination of the deposited a-Si:H film [4–6]. It has been established that when a-Si:H is deposited on Na-containing glass its electrical conductance is not stable, but gradually increases under the applied electric field [5,6]. On the other hand, the preparation of optical glass waveguide consists in the modification of the near-surface region of the substrate by changing its chemical composition. The optical waveguides in glass are usually prepared by an exchange of Na ions with Ag or K ones. Since such a modification leads to a decrease of Na concentration at the substrate surface, one might expect a lower contamination of the deposited films with Na. Therefore, the electrical instability in a-Si:H films deposited on optical waveguides should diminish or even disappear.

In the present work we study the electrical conductance of a-Si:H in relation with the Na concentration at the surface of the soda-lime glass (SLG) substrate. The Na concentration is determined by means of elastic recoil detection analysis (ERDA). The near-surface region of the glass substrates has been modified either by Na extraction or by preparing ion-exchanged waveguides.

## 2. Experimental

SLG with composition in weight percentage: SiO<sub>2</sub> – 73.83, Na<sub>2</sub>O – 14.50, CaO – 5.77, MgO – 4.21, Al<sub>2</sub>O<sub>3</sub> – 0.98, K<sub>2</sub>O – 0.35, Fe<sub>2</sub>O<sub>3</sub> – 0.09, and traces – 0.27, was used as substrate. The Ag<sup>+</sup>-Na<sup>+</sup> or K<sup>+</sup>-Na<sup>+</sup> ion exchange was used for the preparation of optical waveguides. A typical experimental technique was used for each exchange procedure. The Ag<sup>+</sup>-Na<sup>+</sup> ion exchange was carried out by the thermal ion exchange at 350°C, using the mixture of 10-mole % AgNO<sub>3</sub> and 90-mole % NaNO<sub>3</sub> melts as Ag source. The K<sup>+</sup>-Na<sup>+</sup> ion exchange was carried out at the same temperature by employing the field-assisted technique. The applied electric field was 19 V/mm, the anode was the KNO<sub>3</sub> melt, the cathode was the NaNO<sub>3</sub> melt. In addition, some glass substrates were modified without forming optical waveguides as Na ions were extracted from the near-surface region. In this case an Al film was used as the anode. The Na ions from the near-surface region were extracted by the applied electric field into the NaNO<sub>3</sub> melt cathode and a Na-depleted layer was formed on the glass surface under

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the Al anode. The applied electric field was 88 V/mm, the temperature was 350°C. The Al film was deposited on the substrate by thermal evaporation and was etched off before the a-Si:H film deposition. The effective thickness of the optical waveguides was estimated from the refractive index profiles and was 8 and 3  $\mu\text{m}$  for Ag and K waveguides, respectively. The thickness of the Na-extracted region was about 5  $\mu\text{m}$ .

a-Si:H films were deposited by PECVD using 10%  $\text{SiH}_4$  in hydrogen, at a substrate temperature of 270°C, a pressure of 65 Pa, and an applied RF (13.56 MHz) power of 28 W. The films deposited on the Na-free Corning 7059 glass substrates were used as reference. The film thickness was about 600 nm.

The electrical conductance of a-Si:H films was measured using Al coplanar electrodes with separation of 0.5 mm. The measurements were carried out at room temperature, applying a dc voltage of 5 V. The electrical current was measured with an electrometer.

The atomic density and the depth distribution of Na were measured by means of Heavy Ion ERDA (elastic recoil detection analysis). The samples were bombarded with 35 MeV Cl ions from the Rossendorf 5 MV tandem accelerator [7]. The ions hit the samples under a glancing angle of 15° relative to the surface. The elastically scattered ions and recoiled target atoms were detected under a forward direction with a Bragg ionisation chamber described by Hentschel *et al.* [8]. This chamber was placed under 30° with respect to the ion beam and separated the recoiled particles and scattered ions according to their atomic number and energy. From the energy spectra of each separated element its depth distribution could be calculated with a special computer code [9] using the semi-empirical stopping power values of Ziegler *et al.* [10] and the Rutherford cross section data.

### 3. Experimental results and discussion

Figure 1 shows the plots of electrical conductance versus measurement time for a-Si:H films deposited on the original SLG substrate and on the Corning 7059 glass substrate. The great difference in the obtained dependencies is due to the Na contamination of films on SLG substrate. It is not clear what is the mechanism controlling the Na transport from the substrate into the growing film. It might be the thermal Na in-diffusion during the film growth, or the recently proposed mechanism of ion exchange between the alkali in glass and the protons in film [4]. It has been shown for a-Si:H films on SLG substrate that the increase in the electrical conductance with the measurement time is more pronounced at the elevated measurement temperatures and becomes steeper for the higher values of the electrical bias. The inference has been drawn that the mechanism responsible for the observed instability is the bias-enhanced doping efficiency of Na in a-Si:H [5].

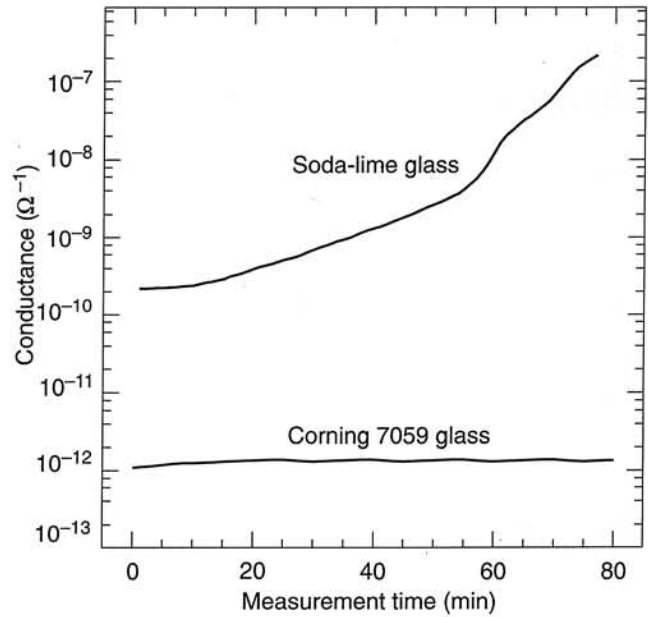


Fig. 1. The plots of electrical conductance vs. measurement time for a-Si:H films deposited on soda-lime and Corning 7059 glass substrates.

No traces of Na in a-Si:H films have been detected by ERDA, which suggests that the Na concentration in the films is below 0.1 at%. However, ERDA has provided evidence that there is Na migration in the near-surface region of the glass substrate under the action of the a-Si:H growth conditions. Figure 2 shows the change in the Na depth distribution at the surface of the original glass substrate due to a-Si:H deposition. Curve 1 corresponds to the initial Na distribution in the substrate. Curve 2 has been obtained after the a-Si:H film was etched off. The difference between

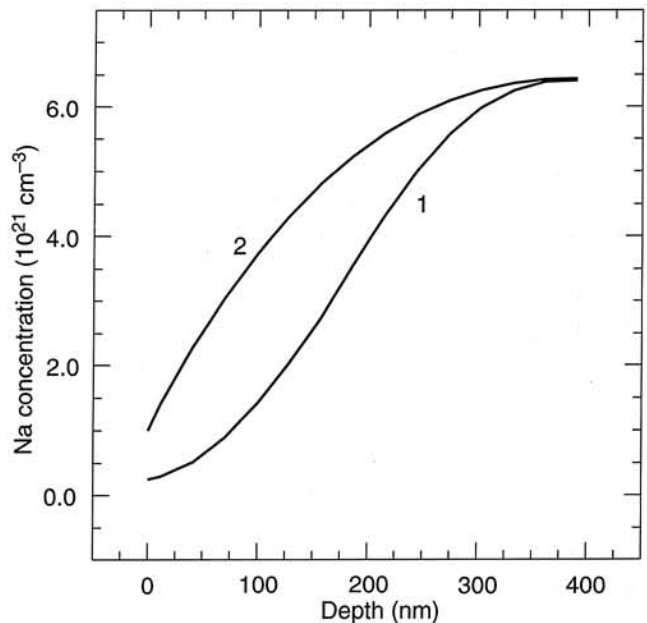


Fig. 2. Na distribution in SLG substrates before (1) and after (2) a-Si:H deposition.

the curves suggests that during the film deposition Na migrates in the glass substrate toward its surface. Apart from the details of the migration mechanism one can assume that the detected increase of Na concentration in the near-surface region of the glass substrate displays a process, another consequence of which is the penetration of Na into the a-Si:H, as it is registered by the electrical instability of the films (Fig. 1).

Figure 3 shows the plots of conductance versus measurement time for a-Si:H films deposited on the ion-exchanged and Na-extracted glass substrates. The data for films on Corning 7059 glass substrate are given for comparison (curve 1). It is seen that there is a gradual increase in the electrical conductance when the a-Si:H is deposited on Ag waveguide (curve 2). The increment is significantly lower as compared with films on the unmodified glass substrate, which is probably related with a lower Na contamination of the deposited a-Si:H (Fig. 1). In the films deposited on K waveguides and on Na-extracted substrates the electrical conductance is constant under the applied electric field (curves 3 and 4), i.e. these films are as stable, as the reference samples with the Na-free Corning 7059 glass substrate.

Figure 4 shows the Na distribution in the surface region of about 400 nm for the substrates used for a-Si:H deposition. The ERDA measurements were carried out after the a-Si:H films were etched off. It is seen that both  $\text{Ag}^+ \text{Na}^+$  and  $\text{K}^+ \text{Na}^+$  ion exchange lead to a strong decrease of Na in the surface region, but its concentration is higher in Ag waveguides (curves 2 and 3). Besides, in Ag waveguides the Na concentration at the surface is close to that of the original (unmodified) substrate, which suggests that Na

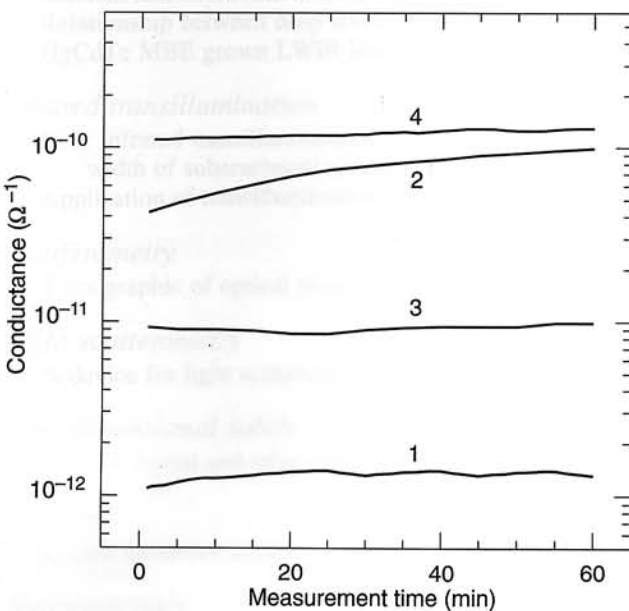


Fig. 3. The plots of electrical conductance vs. measurement time for a-Si:H films deposited on: (1) – Corning 7059 glass substrate and on SLG substrates with (2) – Ag waveguide; (3) – K waveguide; (4) – Na-extracted surface layer.

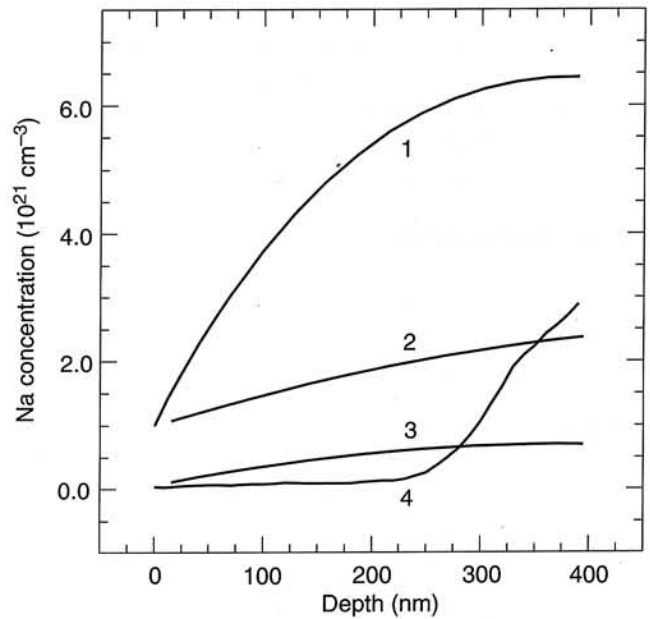


Fig. 4. Na distribution in SLG substrates with: (1) – original surface; (2) – Ag waveguide; (3) – K waveguide; (4) – Na-extracted surface layer.

could have penetrated into the film (curves 1 and 2). This suggestion is in consistency with the results of the electrical measurements shown in Fig. 3. The lowest Na concentration, with a value close to the detection limit, is in the surface region of the glass substrate, which has been modified by Na ion extraction. In this case the Na depletion is deep in a relatively thin near-surface region, as the Na concentration starts sharply to increase at a depth of about 250 nm (curve 4).

Comparing the data in Figs. 3 and 4 one can conclude that in order to avoid the Na contamination of the deposited films it is sufficient to create a relatively thin Na-free near-surface region in the glass substrate.

The obtained results point out that concerning the issue of integration of a-Si:H-based devices with waveguide structures in SLG the preparation procedure of the optical component plays an essential role. When the optical waveguides are prepared by the field-assisted ion-exchange and are with a step-like refractive index profile and the Na concentration at the substrate surface is strongly reduced, the integration with a-Si:H-based devices is expected to be successful. When optical waveguides are prepared by a pure thermal process which leads to a gradual refractive index profile the amount of Na at the substrate surface is still enough to penetrate into the a-Si:H and affect its electrical stability.

#### 4. Conclusion

The present study suggests that a-Si:H-based devices could be integrated with the optical waveguides prepared in soda-lime glass. The necessary condition for a successful integration is a strong Na depletion of the substrate surface.

From this point of view the optical waveguides with gradual index profile are not suitable, because there is still enough Na which can penetrate into the deposited films. In this case the Na contamination of the a-Si:H films can be avoided by preparing buried optical waveguide using ion extraction from the near-surface region.

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