Laser crystallization of silicon on lithium niobate

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Abstract: Localized laser heating of amorphous Si deposited on $LiNbO_3$ results in crystallization of the Si over-layer and the formation of a waveguide in the $LiNbO_3$ substrate that supports guided modes in the visible and IR.
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1. Introduction

Silicon is well known to be an exceptional electronic material, though more recently it has found interest by several research groups for its potential role in the area of photonics [1]. One of the key attractions of Si is that it benefits from the mature processing technology which has been developed for the microelectronics industry. However, in terms of its optical properties it has several fundamental drawbacks mainly associated with the lack of electro-optic and second order nonlinear optical capability. Lithium niobate ($LiNbO_3$), on the other hand, has an excellent pedigree as an electro-optic and nonlinear optical material [2] and is widely used in the photonics industry for optical switching and nonlinear wave mixing applications. Combining these very important technological materials could produce composite systems that will benefit from the complimentary properties of the constituents.

Here we present results of such a composite system, which is formed by the laser annealing of amorphous silicon (a-Si) thin films, which are deposited onto ferroelectric $LiNbO_3$ single crystal substrates. We demonstrate that local heating induced by absorption of c.w. laser radiation at visible wavelengths not only results in annealing and crystallization of the a-Si layer [3], but also produces an optical channel waveguide in the underlying crystal.

2. Experimental procedures

The $LiNbO_3$ crystal substrates used in these experiments were diced out of a congruently melted z-cut wafer with a thickness of 500 μm. The composite samples were produced by deposition of a-Si using plasma enhanced chemical vapor deposition (PE-CVD) onto the polar (z) faces of the substrates. The thickness of the deposited a-Si film was of order 200-250 nm and was uniform across the surface of the sample. In some cases the samples were thermally annealed to remove any residual hydrogen form the a-Si film resulting from the PE-CVD process.

The samples were scanned under the focused beam of an argon ion laser (λ=488 nm) using a set of high precision linear translation stages (Aerotech ABL-1500). The scanning was performed in a linear fashion to form sets of straight laser-irradiated tracks. The scanning speed was varied from 0.06-6 mm/s and the focused laser spot diameter was of order ~2-5 μm. The laser intensities used in these experiments was in the range of 0.60-3.5GW/cm^2.

3. Results and discussion

Visible radiation is strongly absorbed by the a-Si layer resulting in rapid heating of the film to high temperatures, which for certain irradiation conditions reach the melting point for this material. This is due to the fact that the thermal energy is confined within the film area, as the substrate ($LiNbO_3$) is a poor heat conductor. Additionally, heat transfer across the film is limited due to the small thickness of the film.

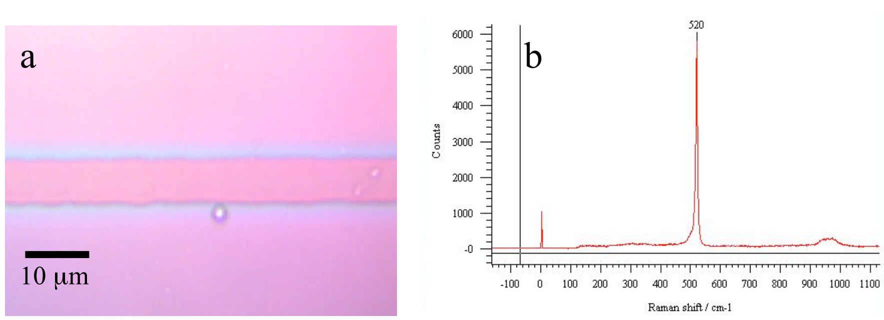

Fig 1. a) Optical microscopy image of a laser irradiated track on a-Si deposited on $LiNbO_3$. b) Raman spectrum corresponding to the laser irradiated portion of the a-Si film.

Optical microscopy observation of the irradiated tracks revealed that the heated area was confined largely to the area of the focused laser spot, as shown in Fig 1a. The optical contrast of the irradiated material with respect to the surrounding film is consistent with a change in the volume of the heat-treated part of the film, which indicates that some crystallization of the deposited a-Si has taken place.

Further proof that crystallization of the a-Si film has taken place in the irradiated area is given by Raman spectroscopy. The Raman spectrum shown in Fig 1b has been taken from the heat-treated area of the film showing a very narrow spectral line centered around 520 cm^{-1}, which corresponds to poly-crystalline Si. The surrounding material exhibits the characteristic broad Raman peaks that are associated with a-Si

Another interesting result obtained from the laser-annealed composite is the formation of a channel waveguide on the $LiNbO_3$ substrate directly underneath the irradiated a-Si track. The resulting channel waveguide was able to support both TE and TM modes although the best transmission results were obtained for TM modes, which corresponds to a significant change of the extraordinary refractive index of the crystal. Fig. 2 shows near field mode profiles that were obtained by the laser irradiated $LiNbO_3$/a-Si composite in the visible (633 nm) and IR (1523 nm) spectral region. As expected the waveguide is highly multimode in the visible but single mode in the IR.

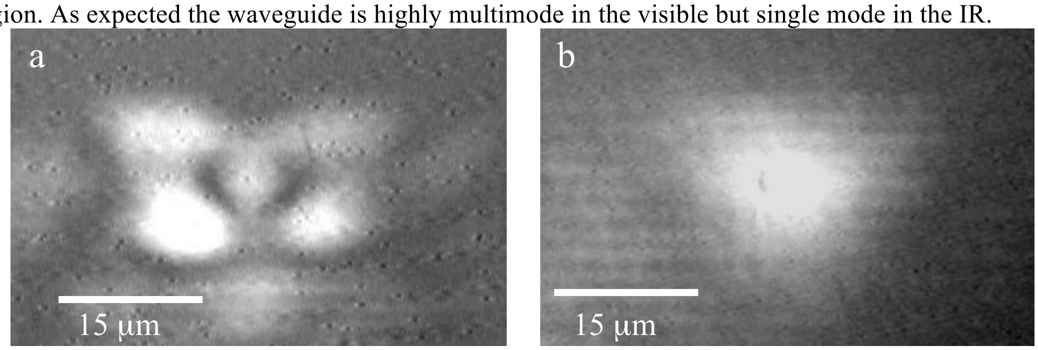

Fig. 2. Near field mode profiles at 633 nm (a) and at 1523 nm (b) obtained from a waveguide in $LiNbO_3$ underneath a laser irradiated track on the a-Si over-layer.

The experimental evidence, which has been gathered so far, suggests that the waveguides that are formed in the substrate originate from a stress field, which is associated with the localized heating of the a-Si over-layer. It is important to note that the melting temperature of the over-layer is higher than that of $LiNbO_3$, which means that it is likely that a surface layer of the substrate Experiences liquid state during the irradiation process. The resulting stress can therefore be associated with a mismatch in the thermal expansion between Si and $LiNbO_3$ upon re-solidification.

4. Conclusions

Irradiation of an a-Si/$LiNbO_3$ composite using a c.w. laser induces crystallization of the a-Si over-layer while at the same time produces an optical channel waveguide in the $LiNbO_3$ substrate. These results are promising a practical route for combining the electronic and photonic functionalities that are associated with Si and $LiNbO_3$, respectively, in a single composite material system. We expect that such composites will find use for the fabrication of efficient compact electro-optic devices.

4. References

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