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Ion-induced pattern formation on indium tin oxide for alignment of liquid crystals

T. Škereň [a,b,*], D. Doornaert [c,d], C. Glorieux [c], H. Modarresi [a], T. Guan [e], K. Temst [a], W. Vandervorst [a,f], A. Vantomme [a]

[a] Instituut voor Kern-en Stralingsfysica, KU Leuven, Celestijnenlaan 200D, B-3001 Leuven Belgium
[b] Czech Technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering, Břehová 7, 115 19 Prague 1, Czech Republic
[c] Laboratory for Acoustics and Thermal Physics, Department of Physics and Astronomy, KU Leuven, B-3001 Heverlee, Belgium
[d] Wave Propagation and Signal Processing Research Group, KU Leuven Campus Kortrijk, E. Sabbelaan 53, B-8500 Kortrijk, Belgium
[e] Departement Elektrotechniek ESAT-MICAS, KU Leuven, Kasteelpark Arenberg 10, B-3001 Leuven, Belgium
[f] IMEC, Kapeldreef 75, B-3001 Leuven, Belgium

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ABSTRACT

Indium tin oxide (ITO) is broadly used as a transparent conducting material for electrodes in optoelectronic devices. Irradiation of ITO with low energy ions can result in the formation of periodic surface nanopatterns which can serve as an alternative for the polymer alignment layer in liquid crystal devices. We investigated the formation of the ion-induced surface nanopatterns on ITO with focus on the influence of the crystalline structure of the material. We find that the crystallinity plays a crucial role in the pattern formation, with no pattern developing on an amorphous ITO surface. We discuss these findings in the context of the state-of-the-art theory for ion-induced patterning. We show that the ion-induced pattern plays a critical role in the liquid crystal alignment on ITO surfaces.

1. Introduction

Irradiation of surfaces with low energy ions often leads to the formation of periodic surface nanostructures [1–4]. This phenomenon has recently attracted a lot of attention as a potentially powerful tool to fabricate surface nanostructures on large scale areas for various purposes [5–9]. Among the wide variety of applications, several studies demonstrated the possibility to use the ion-induced nanostructures for the alignment of liquid crystals [7,8,10–13].

Currently, liquid crystal (LC) optoelectronic device fabrication represents a massive and still growing industry. Substantial effort in this area is dedicated to the development of technology to improve the performance of the devices and simplify and reduce the costs of the fabrication process. LC devices rely on the optical anisotropy of a nematic liquid crystal layer, whose director needs to be strongly and uniformly aligned. In the absence of an electric field, planar alignment is typically achieved by orienting forces at the interfaces between which the LC is sandwiched. Switching on an electric field then induces a competitive orienting force, leading to a homeotropic or twisted nematic director pattern. A crucial task in the LC device fabrication is the treatment of the interfaces.

The most common industrial way of achieving this is by 1) depositing a polyimide (PI) thin film on the desired surface and 2) mechanically rubbing it in a specific direction. The rubbing process induces grooves along the polymer surface, resulting in an anisotropic surface texture, and alignment of LC molecules nearby the surface with the director along the rubbing and groove direction. One of the alternatives for this process is ion-induced patterning [8,10–12,14,15]. This technique is capable of producing an anisotropic nanoscopic surface morphology and surface anchoring of the LC molecules, and thus induce anisotropic alignment.

Ion-irradiation induced LC alignment has been applied on polyimide coated surfaces [8,10]. The PI film is usually deposited directly on the (transparent) electrodes of the LC devices, which are typically made of indium-tin-oxide (ITO). However, in the fabrication process, the deposition of PI represents an additional processing step, which could be avoided if the LC alignment was achieved directly by the ITO surface. Ion-induced nanopatterning of ITO thus has a high application potential in the LC device industry.

In this paper we study in detail the pattern formation on different ITO surfaces subjected to grazing incidence ion irradiation. At these conditions, formation of ripples parallel to the ion beam direction (so-called perpendicular mode ripples (PeMR) due to the orientation of the ripple

* Corresponding author at: V Holešovičkách 2, Praha 7, Czech Republic. Tel.: +420 221 912 817; fax: +420 284 684 818.
E-mail address: tomas.skeren@fjfi.cvut.cz (T. Škereň).

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wavevector) has been observed [5–7]. Formation of PeMR structure is typically associated with metallic surfaces while for amorphizable surfaces this ripple mode is either not present at all or the ripple pattern has very low quality. Specifically, we compare the PeMR pattern formation on amorphous and polycrystalline ITO and we conclude that the crystalline structure strongly influences the ripple pattern formation. These results are discussed in the context of the existing theory for the ion-induced patterning and possible causes for the dramatic difference between the patterning of amorphous and polycrystalline ITO are identified. It is also shown that the ion-induced morphology plays a critical role in the liquid crystal alignment.

2. Experimental details

We investigated the pattern formation on two different ITO samples. The polycrystalline Sample A was a sputter-deposited ITO film with a thickness of 240 nm purchased from Sigma-Aldrich. The amorphous Sample B was prepared by sputter-deposition at room temperature without any post-growth thermal treatment. The thickness of sample B, measured by Rutherford backscattering spectrometry, was 400 nm. This value may be somewhat underestimated since the possible porosity of the samples was not taken into account. The precise film thickness is, however, not critical for the current study.

Ion irradiation was performed with a 5 keV Ar^+ ion beam coming from an electron ionization ion gun. A weakly focused (~0.5 mm) ion beam with the current of 2.5 μA was scanned over an area of 9×9 mm^2. In order to achieve identical irradiation conditions, the two samples were placed next to each other on the same sample holder and irradiated simultaneously. Characterization of the sample surface was performed in situ by a scanning tunneling microscope (STM) prior to the irradiation and then after each irradiation step.

In order to investigate the liquid crystal alignment, two (identical) surfaces were put together facing each other and separated by a sheet spacer with a thickness of 20 μm. In the case of ion-irradiated surfaces the cells were assembled such that the irradiation directions of the two surfaces were anti-parallel. A droplet of E7 LC mixture was placed at the edge of the cell cavity, leading to capillary filling of the the cavity with the LC. The LC alignment in the cavity was then investigated by polarized light microscopy. E7 is a uniaxial positive liquid crystal with ordinary and extraordinary refractive index of 1.52 and 1.74 respectively.

3. Results

3.1. ITO film characterization

Figs. 1 and 2 respectively show the initial surface morphology of the two films and the $\theta - 2\theta$ X-ray diffraction (XRD) pattern of the two

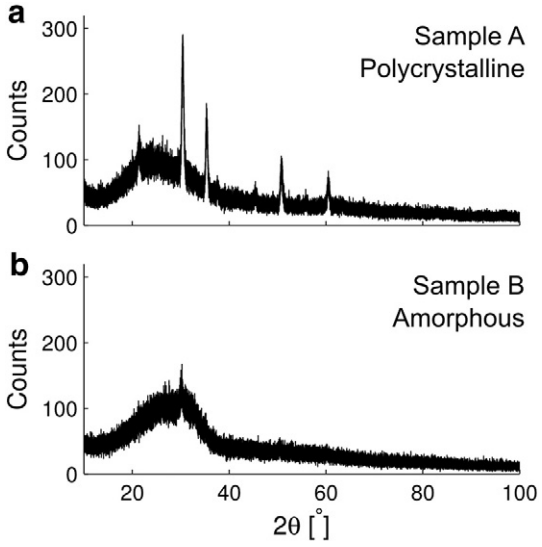

Fig. 2. θ–2θ XRD scans of a) sample A and b) sample B.

films (measured with Cu K-α X-ray source). The broad peak in the XRD pattern (between ~15°–40°) corresponds to the amorphous glass substrate. The strongest ITO diffraction peak is expected at 30.5° [16]. The XRD pattern of sample A reveals pronounced crystalline peaks while in the pattern of sample B only the strongest ITO peak is detectable, but with a substantially lower intensity. Since the layer thickness of the amorphous sample B was almost twice as large as the one of sample A, this implies that the amount of crystalline ITO in sample B was substantially smaller than in sample A. These observations are in agreement with previous studies on the crystalline structure of ITO surfaces sputter-deposited at different temperatures. [17–23].

The initial root mean square (RMS) roughness measured by STM is 2.2 nm for sample A and 3.4 nm for sample B.

3.2. Ion-induced pattern formation

Samples A and B were simultaneously irradiated by a grazing incidence 5 keV Ar^+ ion beam with gradually increasing ion fluence. The ion beam angle of incidence was 80°, measured from the surface normal (i.e. grazing incidence). STM topographs of the two surfaces after ion irradiation are presented in Fig. 3. A pronounced ripple pattern was formed on the surface of sample A with a direction parallel to the ion beam projection to the sample surface. This topography is visible even at the lowest ion fluence – 121 ions · nm^{-2} – and remains visible and comparable until the highest fluence studied here — 484 ions · nm^{-2}.

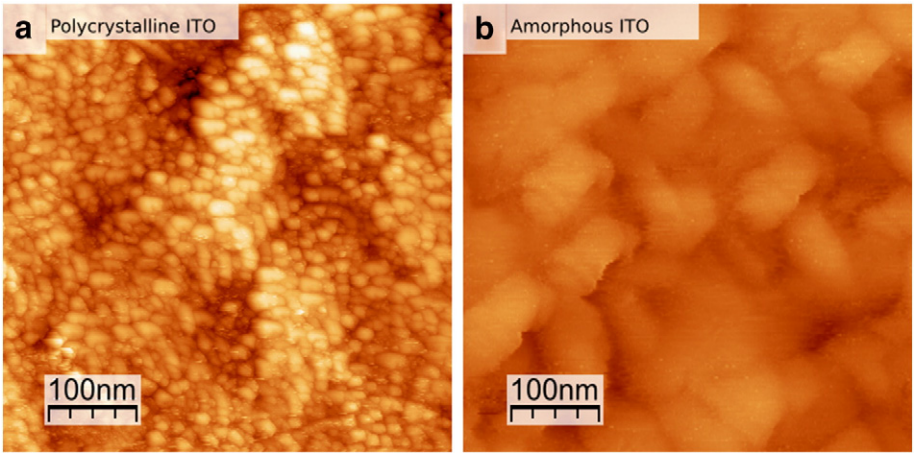

Fig. 1. Initial surface morphology of a) polycrystalline (sample A) and b) amorphous (sample B) ITO.