Thin Solid Films 517 (2009) 5553–5556

Contents lists available at ScienceDirect

Thin Solid Films

journal homepage: www.elsevier.com/locate/tsf

Retardance of chalcogenide thin films grown by the oblique-angle-deposition technique

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ARTICLE INFO

Article history:
Received 28 August 2008
Received in revised form 20 March 2009
Accepted 25 March 2009
Available online 5 April 2009

Keywords:
Oblique angle deposition
Retardance
Chalcogenide
Polarizer

ABSTRACT

Columnar and chevronic thin films of GeSbSe chalcogenide glasses were grown by the oblique-angle-deposition technique. These thin films were found to exhibit dielectric anisotropy in the near-infrared regime. The retardance of any of the fabricated thin films was found to increase linearly with the thickness. Columnar thin films exhibited significantly lower retardance per unit thickness than chevronic thin films. The experimental results indicate the potential of these thin films for near-infrared polarizers.

1. Introduction

Chalcogenide glasses containing sulfur or selenium as major constituents are of recent interest to technoscientists due to their optical transparency in the near-infrared regime, a property which is useful for many applications in the fields of infrared optics, optical signal imaging and data storage [1,2]. Glasses are preferred over crystalline materials of equivalent composition because of their homogeneity, intrinsic isotropy, and specific mechanical properties that enhance manufacturability. Indeed, chalcogenide glasses can be vapor deposited in amorphous form by several methods, including the oblique-angle-deposition (OAD) technique [3–5]. For more than a century, the OAD technique has been used to create effectively anisotropic materials for optical and infrared applications [6–8]. The anisotropy is due to the columnar morphology of the deposited material: highly collimated vapor condenses on a planar substrate to form an ensemble of nominally parallel and nominally identical columns with cross-sectional dimensions in the 30-to-300 nm range [9–12].

Retardance plates for operation in the visible regime have been fabricated by the oblique-angle deposition of various inorganic thin films [8,13]. Motivated by the prospects of realizing retardance plates for operation in the 1200-to-2400-nm wavelength regime, in this brief communication we report the fabrication of columnar and chevronic thin films of GeSbSe chalcogenide glass, the measured retardances of these thin films, as well as their near-infrared transmittance spectra for linearly polarized light.

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doi:10.1016/j.tsf.2009.03.200

2. Experimental details

Columnar and chevronic thin films were grown on double-sided polished monocrystalline silicon substrates by evaporating commercially available bulk chalcogenide glasses with the composition $Ge_{28}Sb_{12}Se_{60}$ (TI 1173, Texas Instruments). Before the deposition, each substrate was cleaned with acetone and ethanol, then dried with nitrogen, and then quickly loaded into the vacuum chamber. The chalcogenide thin films were deposited by thermal evaporation at room temperature and at a typical base pressure of ~6.67×10^{-5} Pa. The stationary substrate was oriented for columnar thin films so that the average direction of the collimated vapor was 0°, 15°, 45°, 60° or 70° with respect to the normal to the substrate. The thickness of the resulting chalcogenide thin films ranged from 500 nm to 4.7 µm, the thickness being a function of the direction of the collimated vapor and the duration of evaporation. For the chevronic thin films, the average direction of the collimated vapor was changed from, say 60° to −60° or vice versa, after fixed intervals.

High-resolution cross-section morphological characterization was performed by the use of a Leo 1530 Field Emission Scanning Electron Microscope (FESEM), equipped with a thermal field emitter source with operating voltages ranging from 200 eV to 30 kV. This system is capable of resolving 1.2 nm at 20 kV, 2.5 nm at 5 kV, and 3 nm at 1 kV operating voltage.

In order to measure the retardance of the columnar and chevronic thin films, a Soleil-Babinet compensator (SBC-IR, Thorlabs Inc.) was used between a pair of crossed Glan-Thompson polarizers in a classic generator/analyzer configuration. A 1310-nm laser diode was used for the measurements. As shown in Fig. 1, the thin film was mounted on a rotation stage and inserted between the polarizer and the

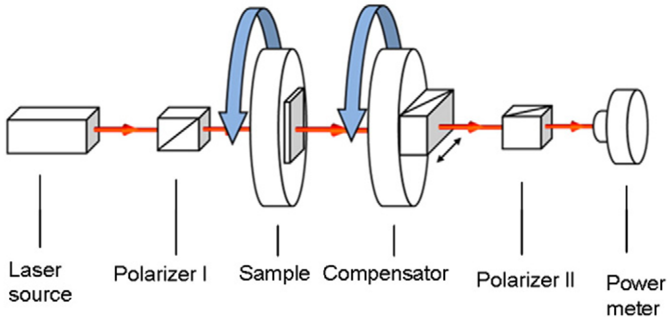

Fig. 1. Experimental setup for measuring the retardance of a columnar or chevronic thin film consisting in the following components (from left to right): (1) light source, (2) Glan-Thompson polarizer, (3) sample, (4) Soleil-Babinet compensator, (5) Glan-Thompson analyzer, and (6) Power meter.

compensator. When the fast optical axes of both the thin film and the compensator were oriented at 45° with respect to one of the polarizer transmission axes, the retardance of the thin film was measured by adjusting the slab thickness of the compensator to extinguish the transmitted light spot detected by the power meter. Before each measurement, the sample was rotated to align its fast optical axis with the optical axis of one of the two polarizers. Also, during the measurements the optical axes of the two polarizers were crossed. The error tolerance of the experimental setup used is ±0.36°.

Transmittance spectra in the 1000-to-2400 nm wavelength range were recorded with a Perkin Elmer Lambda 950 UV/vis/NIR spectrophotometer. The resolution of the spectrophotometer is better than 0.20 nm with a wavelength accuracy of ±0.30 nm.

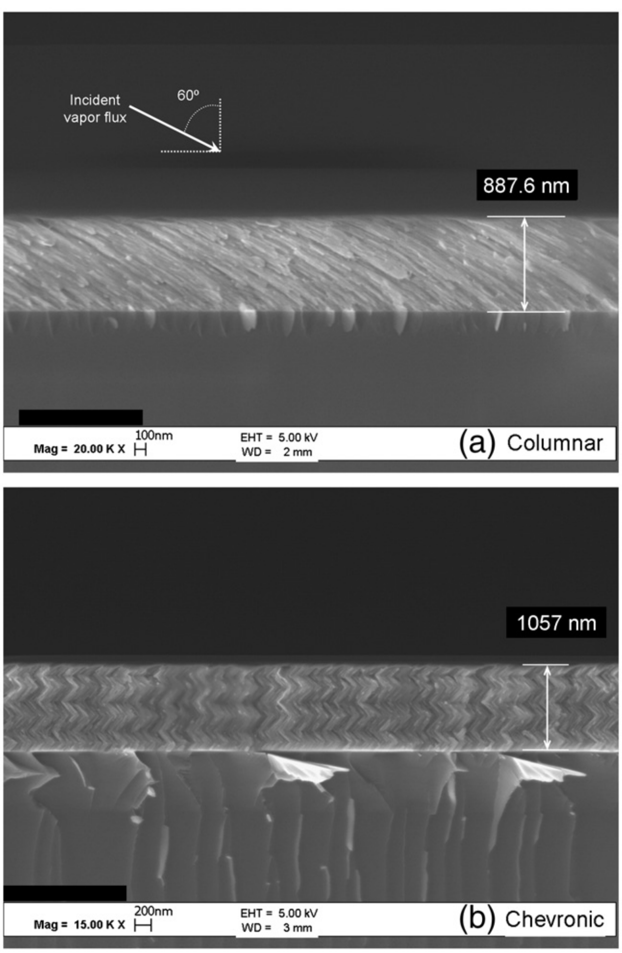

Fig. 2. Cross-sectional FESEM images of (a) a columnar thin film grown by directing vapor at 60° to the normal to the substrate, and (b) a chevronic thin film grown by alternating the vapor deposition angle between +60° and −60°. Both thin films of chalcogenide glass were deposited on silicon substrates. The thicknesses of the thin films are 887.6 nm (columnar) and 1057 nm (chevronic). This chevronic thin film may be considered as a cascade of 7 columnar thin films.

3. Results and discussion

Fig. 2a shows a cross-sectional FESEM image of a typical columnar thin film of chalcogenide glass grown on a silicon substrate by directing the collimated vapor at an angle of 60° to the substrate normal. The tilted columnar morphology of the columnar thin film is clearly evident in the image, with the cross-sectional diameter of the columns roughly 70 nm. After neglecting nonspecular reflection and transmission, such columnar thin films are expected to be optically equivalent to a biaxial crystal [8], and therefore must discriminate between the two orthogonal linearly polarized states of light, particularly for free-space wavelengths that are considerably (>10 times) longer than the cross-sectional diameter of the columns in the thin films.

Retardance measurements at 1310-nm wavelength were performed on several columnar thin films of various thicknesses. The results are shown in Fig. 3. Columnar thin films grown with vapor directed normally towards the substrate (i.e., at a vapor incidence angle of 0°), showed no retardance as expected. This is because the columns are then of approximately circular cross-section so that there is no geometric anisotropy in any plane parallel to the substrate [8,9,14]. For vapor incidence angles other than 0°, the columns become somewhat elliptical in cross-section, and therefore non-zero retardances up to 60° vapor incidence angle were measured for columnar thin films up to 4 μm in thickness.

As can be observed from Fig. 3, when the vapor incidence angle was increased beyond 60° (i.e., to 70°), higher retardance was not obtained. Our experimental data suggest that the dielectric anisotropy parallel to the substrate plane is maximum when the vapor incidence angle is ~60°. This observation is in accord with the measurements of Hodgkinson et al. [15] at 633-nm wavelength on columnar thin films of inorganic oxides deposited at vapor incidence angles less than or equal to 70°.

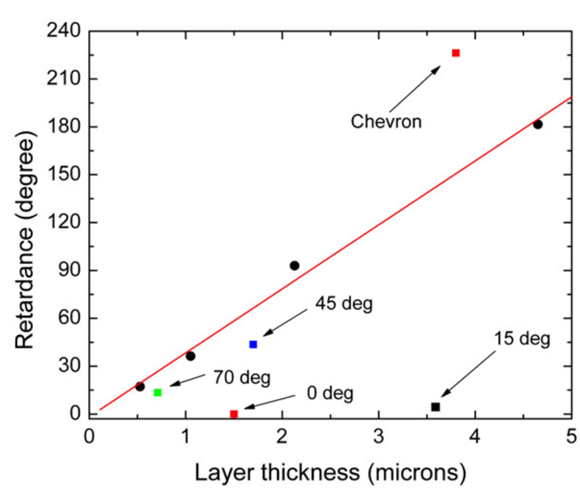

Fig. 3. Retardances measured at 1310-nm wavelength of columnar thin films of different thicknesses grown by directing chalcogenide-glass vapor at different incidence angles with respect to the substrate normal. The dots correspond to columnar thin films grown at an evaporation angle of 60°. For other columnar thin films, the labels indicate the vapor incidence angle. The chevronic thin film comprises seven 0.54-μm-thick columnar thin films grown with vapor incidence angles alternating between +60° and −60° (see text and Fig. 2b).