Chalcogenide cylindrical helix nanocollumnar thin films for switchable polarization effects

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Abstract: Phase change material $Ge_2Sb_2Te_5$ tilted and helical nanorods films featuring 25 nm diameters are grown using the oblique and glancing angle deposition techniques. We provide insights on the growth process, structural integrity and optical responses.

1. Introduction

A great deal of efforts have been devoted to achieving nanostructured thin films for applications in optics. Electron beam lithography is an ideal method for achieving such features, but is expensive, time-consuming and thus not suitable for industrial implementation. Alternatively, a novel and robust technique for engineering three dimensional nanocollumnar thin films with nanorod diameters of a few molecules across is the oblique angle deposition (OAD) technique. At such small length scales extremely high plasmonic enhancement is achievable, in addition to quantum light matter interactions. For over 100 years OAD has been of keen interest in the thin film community owing to resulting devices possessing enhanced dichroism, birefringence, and anisotropic optical properties. By tilting the substrate during deposition such that the incident flux of atoms is oriented at a steep angle, porous nanorod thin films grow through a shadowing effect created by the incident adatoms. Sophisticated subwavelength zig-zag and spiral nanorods can be engineered by translating or rotating the substrate during deposition, this is more commonly referred to as the glancing angle deposition (GLAD) technique.

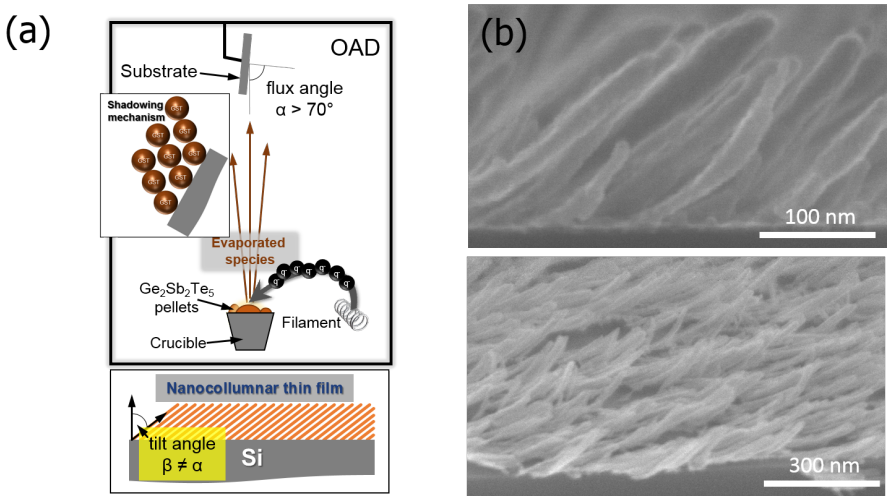

Fig. 1. (a) Schematic diagram of growth process, (b) SEM images of GST nanorods grown at cryogenic temperatures.

A gamet of materials have been previously grown with OAD such as metals, dielectrics, organics, transparent conductive oxides, and phase change materials (PCMs) [1–5]. Previous nanorod PCM investigations fail to explore the phase change aspect in the nanocollumnar films. PCMs such as $Ge_2Sb_2Te_5$ (GST) exhibit drastically differing thermal, electrical and optical properties upon a reversible change in molecular arrangement, and are thus attractive for tunable optical displays, meta-optics, and optical memories. In this work, we explore a unique nanopatterning approach to grow GST nanocollumnar films via oblique angle deposition (OAD) and glancing angle deposition (GLAD) techniques [2, 3]. We report film morphology and optical properties in both amorphous and crystalline states to build a foundation for switchable polarization effects.

During the growth process, bulk chalcogenide glass GST pellets were used as the source material to deposit amorphous thin films on to double sided polished silicon and sapphire substrates. The GST films were deposited using an MDC evap-4000 electron beam evaporation with a throw distance of approximately 0.5 m. Samples were mounted at a fixed angle $\alpha = 85^\circ$ with respect to the incident vapor flux on either a metal block held at -183K or a rotation stage kept at room temperature. The deposition rate was kept fixed at 3A/s and the rotation speed ω was varied between depositions. We fixed the effective film height to $\sim$125 nm between depositions. A companion piece was mounted at normal incidence which grew 50% more in thickness. Fig. 1(b) depicts scanning electron microsope (SEM) images of GST tilted nanorods (no rotation during deposition) grown at cryogenic substrate temperatures.

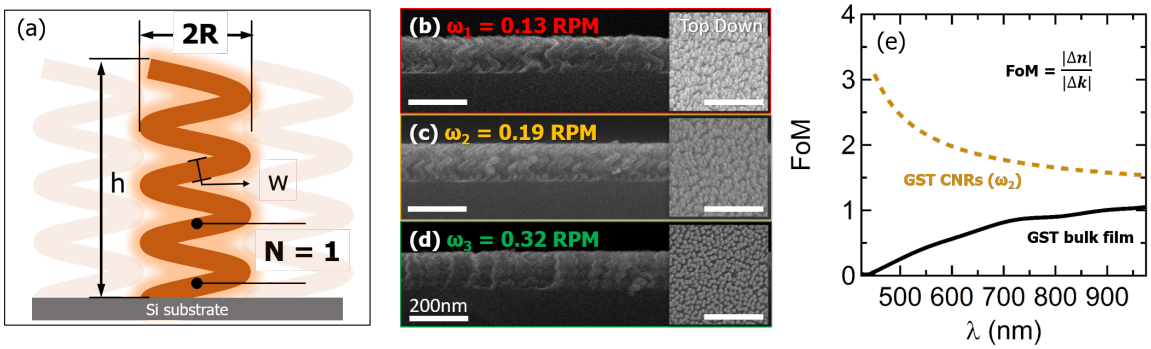

Fig. 2. (a) Schematic diagram, (b)-(d) SEM cross section and top down (insets) images of as deposited GST cylindrical helix nanocollumnar films grown on Si substrates with increasing rotation speeds. All scale bars are 200nm, (e) FoM comparing bulk and chiral nanorods (CRNs).

Chiral nanorods (CRNs) were also fabricated at a room temperature deposition. We were able to tune the pitch and helix diameter of the CRNs by varying the rotation speed during deposition. Figure 2(a) shows a schematic diagram of one cylindrical helical nanorod where h is the effective height of the nanorods, w is the width of the nanorod, which both remained relatively constant from deposition to deposition, R is the radius of the helical structure, and N is the number of helical turns. Cross sectional SEM images of the resulting films for rotation speeds $\omega_1 = 0.13$, $\omega_2 = 0.19$, and $\omega_3 = 0.32$ RPM are shown in Fig 2 (b), (c), and (d), respectively. The insets of each SEM show a top down image of each film, and all scale bars are 200 nm in length. To study the affect of crystallized GST nanorod structures, the samples were annealed in a convectional oven for 20 minutes at 170°C. The results show minimal fusing of neighboring helical nanorod structures. This is a significant attribute since it is well known that films merge together during external heating processes. This fact opens the field for switchable polarization sensitive devices such as dichrosim and optical activity effects. Additionally, ellipsometry was performed on GST CNRs and bulk GST thin film the thin film samples. Across the entire visible regime, GST CNRs exhibit a higher figure of merit (FoM=$|\Delta n|/|\Delta k|$) where Δn and Δk denote the real and imaginary parts of refractive index change induced by the phase transition, respectively. when compared with bulk thin film GST as shown in Fig 2(e). The refractive index contrast and extinction coefficient of the helical films are reduced.

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