OPTICAL PROPERTIES OF NANOSTRUCTURED POROUS THIN FILMS FABRICATED USING GLANCING ANGLE DEPOSITION

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Glancing angle deposition (GLAD) is a thin film fabrication technique that has been developed at the University of Alberta. Films formed by physical vapor deposition (PVD) will exhibit a columnar nanostructure if the incident vapor flux arrives at an oblique angle with respect to the substrate surface. At a glancing angle of incidence (>70°), self-shadowing mechanisms become accentuated, resulting in a highly porous thin film composed of isolated columns that are inclined towards the incoming evaporation flux. The GLAD technique uses computer-controlled substrate motion to shape these isolated columns into advanced structures such as helices, zig-zags, and vertical posts [1-3].

The GLAD technique is very versatile. GLAD films can be formed from insulators, metals, and semiconductors using evaporation, pulsed laser deposition [4], or long throw, low pressure sputtering [5]. To illustrate the versatility of the process, a multilayer GLAD film, formed from SiO_2 and TiO_2, is shown in Fig. 1. GLAD films are also very robust to micromachining and post-processing. For example, filling the pores of a GLAD film with a curable polymer and etching out the original film structure leads to the formation of inverted GLAD coatings [6].

The ability to directly control the film nanostructure on the optical wavelength scale opens the door to numerous optical applications for GLAD films. GLAD has been harnessed to fabricate porous nanostructures such as 3D square spiral photonic crystals [7,8], anti-reflection coatings [9], inverse or helically perforated coatings with optical rotatory behavior [10], and porous helical films embedded with liquid crystals for optical switching [11].

In particular, helical films exhibit circular Bragg phenomena, including selective reflection of circularly polarized light and optical rotation of linearly polarized light. Both properties scale with the thickness and refractive index of the film. By investigating a variety of dielectrics we found that TiO_2 produced a strong optical response because of its large refractive index and high transparency within the visible regime. Further improvements were made by post-deposition annealing to form polycrystalline anatase phases. This effect can also be extended to chiral Si films, designed to operate at telecommunication wavelengths (1310nm, 1550nm).

Helical films are formed by constant substrate rotation. The speed of rotation controls the pitch of the helix and the direction of rotation determines the handedness of the film. By fabricating similar helical films of opposite handedness we observed enantiomorphism, and by tailoring the pitch (or periodicity) of the film, the wavelength-dependence of the optical response was shifted to red, green, and blue wavelengths (Fig. 2). GLAD Rugate filters may be fabricated by periodically altering the density of the porous film nanostructure.

This presentation will review the GLAD process, overview the optical devices recently fabricated, and present the latest results from chiral optical device engineering.

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References:

[1] K. Robbie, M. J. Brett, and A. Lakhtakia, J. Vac. Sci. Technol., **A 13** (1995) 2991.
[2] K. Robbie, M. J. Brett, and A. Lakhtakia, Nature, **384** (1996) 616.
[3] K. Robbie, and M. J. Brett, J. Vac. Sci. Technol., **A 15** (1997) 1460.
[4] D. Vick, Y. Y. Tsui, M. J. Brett, and R. Fedosejevs, Thin Solid Films, **350** (1999) 49.
[5] J. C. Sit, D. Vick, K. Robbie, and M. J. Brett, J. Mater. Res., **14** (1999) 1197.
[6] K. D. Harris, K. L. Westra, and M. J. Brett, Electrochem. Solid-State Lett., **4** (2001) C39.
[7] S. R. Kennedy, M. J. Brett, O. Toader, and S. John, Nano. Lett., **2** (2002) 59.
[8] S. R. Kennedy, M. J. Brett, H. Miguez, O. Toader, and S. John K., Photonics and Nanostructures, **1** (2003) 37.
[9] S. R. Kennedy and M. J. Brett, Appl. Opt., **42** (2003) 4573.
[10] K. D. Harris, J. C. Sit, and M. J. Brett, IEEE Trans. on Nanotechnology, **1** (2002) 122.
[11] J. C. Sit, D. J. Broer, and M. J. Brett, Liq. Cryst., **27** (2000) 387.

Figures:

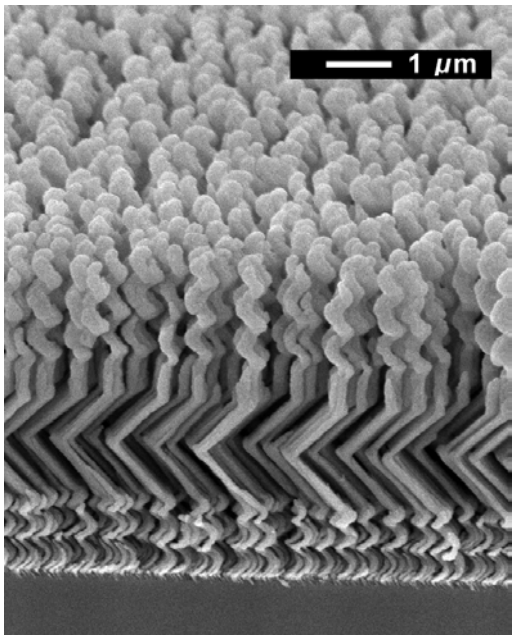

Fig. 1. A multilayer, composite thin film illustrates the versatility of the GLAD process. Starting from the substrate, the layers are:
layer 1: TiO_2 helix, right-handed, 3 turns;
layer 2: SiO_2 zig-zag;
layer 3: SiO_2 vertical posts, 600 nm thick;
layer 4: SiO_2 helix, left-handed, 3 turns.

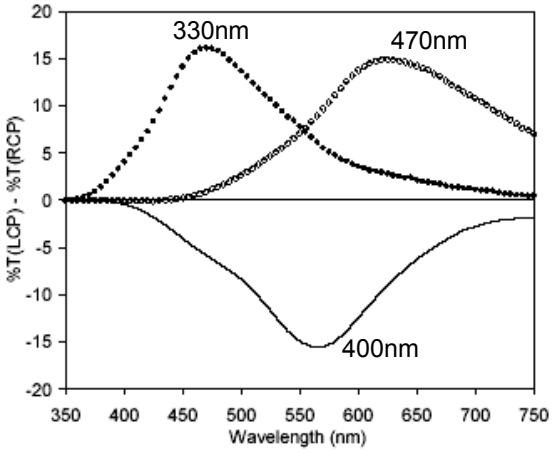

Fig. 2. The handedness and pitch of a helical GLAD film can be used to control the position of the circular reflection band. Plotted from left to right is the selective transmission of three helical TiO_2 GLAD films, with a pitch of 330nm, 400nm and 470nm, respectively. The film in the center is left-handed helix, while the other two are right-handed.