Advanced Surface Engineering Division
Room: 104 - Session SE+TF-TuA

Glancing Angle Deposition (GLAD) II
Moderator: N.A. Beckers, University of Alberta

2:00pm **SE+TF-TuA1 Evolution of Crystal Orientation during Oblique Angle Deposition**, ***G.-C. Wang***, *T.-M. Lu*, Rensselaer Polytechnic Institute **INVITED**

The oblique angle deposition (OAD) has attracted attention due to the shadowing effect that results in interesting morphology of isolated nanostructures. These artificial nanostructures have rich textures depending on the growth conditions such as the angle of incidence, substrate temperature, deposition rate, and substrate rotation speed or mode. These OAD films often have biaxial textures even on amorphous substrates because the in-plane symmetry is broken under the off-normal incidence of the deposited atoms on the substrate. The most frequently used characterization technique for biaxial texture films is x-ray pole figure analysis. However, the texture obtained by x-ray is an average texture from the entire thickness of the film due to the x-ray's few micron penetration depth. As the texture of a film often changes during growth, information on the basic mechanisms that control the final texture is often lost. In this talk we will show how we can use our newly developed reflection high energy electron diffraction (RHEED) *surface* pole figure technique to probe the surface texture evolution of the growth front from the initial stage (a few nm thick) to the later stage of thick films [1] either *in situ* or *ex situ*. Examples of biaxial texture evolution of CaF_2 [2], Mg, W [3] and Mo nanostructures as a function of thickness, incident angle, and rotation schemes, will be presented. The surface sensitive RHEED pole figure technique reveals that biaxial texture can be formed at thickness as small as 20 nm. In some cases, surface texture at the growth front is seen to be quite different from the bulk texture measured by x-ray pole figures. We also show that these biaxial textured films can be used as buffer layers to grow near-single crystal semiconductor films which may find important applications in energy conversion devices.

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[1] F. Tang, T. Parker, G.-C. Wang, and T.-M. Lu, "Surface texture evolution of polycrystalline and nanostructured films: RHEED surface pole figure analysis", Journal of Physics D: Applied Physics 40, R427 (2007).

[2] C. Gaire, P. Snow, T.-L. Chan, W. Yuan, M. Riley, Y. Liu, S.B. Zhang, G.-C.Wang and T.-M. Lu, "Morphology and texture evolution of nanostructured CaF_2 films on amorphous substrates under oblique incidence flux", Nanotechnology 21**,** 445701 (2010).

[3] R. Krishnan, Y. Liu, C. Gaire, L. Chen, G.-C. Wang and T.-M. Lu, Texture evolution of vertically aligned biaxial tungsten nanorods using RHEED surface pole figure technique, Nanotechnology 21, 325704 (2010).

2:40pm **SE+TF-TuA3 Vapor-Liquid-Solid Glancing Angle Deposition (VLS-GLAD): A New Way of Shaping Crystalline Nanowires**, ***A.S. Alagoz***, *T. Karabacak*, University of Arkansas at Little Rock

Vapor-liquid-solid (VLS) is a powerful method enabling fabrication of single crytalline semiconductor nanowires in feature sizes ranging from nano to micro scales. On the other hand, control of nanowire growth direction by using VLS technique is still challenging. In this presentation, we demonstrate a new approach, called vapor-liquid-solid glancing angle deposition (VLS-GLAD), of fabricating crystalline semiconductor nanowire arrays with controlled geometry. VLS-GLAD is a physical vapor deposition based nanowire fabrication technique which relies on selective deposition of source atoms onto metal catalyst nanoislands placed on a crystal wafer. In this technique, collimated obliquely incident flux of source atoms selectively deposit on catalyst islands by using "shadowing effect". Geometrical showing effect combined with VLS growth mechanism leads to the growth of crystalline semiconductor nanowire arrays. In this work, we show the morphological and structural properties of tilted single crystal semiconductor nanowire arrays fabricated by utilizing a conventional thermal evaporation system for VLS-GLAD.

3:00pm **SE+TF-TuA4 Lithographic Processing of Nanostructured Thin Films Grown Using Oblique Angle Deposition Method**, ***P. Shah***, University of Dayton Research Institute, *A. Sarangan*, University of Dayton

It is known that exposing structured thin films (STF) grown using oblique angle deposition (OAD) to liquids such as DI water or any common solvents permanently deforms the physical structure of the thin films and alters their properties. This is a severe limitation of STFs because the films cannot be patterned into useful devices using conventional wet lithographic processes. In this work, we overcome this challenge and propose to demonstrate conventional i-line lithography technique for patterning STF's grown using OAD. The ability to selectively fabricate STF in chosen areas of the active devices will be beneficial for numerous applications. It is shown that the structure of these thin films is preserved after lithographic processing. Processing limits in terms of dimensions of the devices or patterns that may possibly be fabricated are discussed.

4:00pm **SE+TF-TuA7 Automated Measurement Technique for Growth Scaling in Glancing-Angle Deposited Films**, ***J.M. Siewert***, *J.M. LaForge, M.T. Taschuk, M.J. Brett*, University of Alberta, Canada

With growing application of glancing-angle deposition (GLAD) thin films, there is increasing need to understand and engineer GLAD growth mechanics. Devices that make use of GLAD films, such as RH sensors, optical filters, and solar cells require precise knowledge and control of GLAD nanostructure. Typically, GLAD vertical post diameters are described by a power law, $d = w_0h^p$, where d is column diameter, h is height, and w_0 and p are material dependent constants which describe column diameter and broadening, respectively [1, 2]. Based on theoretical growth models, p is expected to range from 5/16 to 1/2. While many GLAD materials have been characterized for p, reliable trends have not yet been obtained [2,3,4,5].

Most groups measure p from cross-sectional SEM images, recording diameters of clearly distinct posts as a function of height. This technique is labour-intensive and large scatter in the data has been observed [4]. One alternative, focused ion-beam cross sections of GLAD films [5], produces very precise measurements but is impractical for characterizing the ensemble properties of a GLAD film. In both cases, the limited number of measurements restricts what can be learned about GLAD films.

To eliminate this limitation, we have been developing an automated characterization method for GLAD posts that enables effective measurement of thousands of posts. Using this technique, we have measured p and w_0 as a function of pitch for 1500 nm TiO_2, 81° deposition angle, vertical post films. We examine post growth for "extinct" and full height posts, discovering markedly different growth scaling behaviors. Characterization of phi-sweep slanted post structures is underway. We will present the optimized technique, current experimental results, and comparisons of automated measurements with existing measurement methodologies.

[1] T. Karabacak, J. Singh, Y.-P. Zhao, G.-C. Wang, and T.-M. Lu, *Phys. Rev. B*, vol. 68, Sep. 2003.

[2] C.M. Zhou and D. Gall, *J. Appl. Phys.*, vol. 103, Jan. 2008, p. 014307.

[3] C. Buzea, G. Beydaghyan, C. Elliott, and K. Robbie, *Nanotechnology*, vol. 16, Oct. 2005, pp. 1986-92.

[4] M.T. Taschuk, K.M. Krause, J.J. Steele, M.A. Summers, and M.J. Brett, *J. Vac. Sci. Technol. B.* vol. 27, 2009, p. 2106.

[5] K.M. Krause, D.W. Vick, M. Malac, and M.J. Brett, *Langmuir*, vol. 26, Nov. 2010, pp. 17558-67.

4:20pm **SE+TF-TuA8 Heterogeneous Nanorod Arrays Fabrication by a Two-Source Dynamic Shadowing Growth System**, *Y.P. He*, ***Y.P. Zhao***, University of Georgia

There are increasing interests in designing and engineering nanostructured materials to improve their performances in various applications. Among many nanostructure fabrication and synthesis techniques, the dynamic shadowing growth can offer an unique advantage by sculpturing nanorod-based structures through computer programing using the self-shadowing effect. The geometry shadowing effect is the dominant growth mechanism resulting in the formation of topologically engineered nanostructure arrays, such as tilted, C-shape, S-shape, *L*-shape, zigzag, matchstick, helical, and vertical nanorods, by programming the substrate rotation in polar and/or azimuthal directions. Such a topological design can be further advanced through compositional engineering. A co-deposition provides a way to evaporate two or more materials simultaneously to form homogeneous composite/doped nanostructures by controlling the relative ratio of the deposition rates of two or more sources. Recently, we have constructed a two-source dynamic shadowing growth (DSG) and demonstrated that various topologically and compositionally engineered nanostructures can be designed by multilayer glancing angle deposition (GLAD) and/or glancing angle co-deposition (GLACD) techniques. Here, we will highlight some of the recent progress in designing heterostructured nanorod arrays through a two-source dynamics shadowing growth system. In particular, Vanadium catalyst doped Mg nanorod arrays fabricated through the oblique angle co-deposition show very different morphology compared to the Mg nanoblades formed by oblique angle deposition. The kinetics of the hydrogen storage performance of the doped Mg nanostructures can be greatly improved compared to that of the Mg nanoblades. The composition-graded CuSi nanorod array can be designed through dynamically changing the deposition rates of the two sources. The Li+ battery performance of these nanostructures compared to that of pure Si nanorods will be discussed.

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