Thin Film

Room: 613/614 - Session TF-WeA

Oblique Angle Deposition

Moderator: M.C.M. van de Sanden, Eindhoven University of Technology, The Netherlands

1:40pm **TF-WeA1 Fabrication of 3D Heterostructured Nanorod/Nanospring Arrays by Dynamic Shadowing Growth**, ***Y.P. He***, *Y.P. Zhao*, University of Georgia

One-dimensional (1D) heterogeneous nanostructures are important building blocks for nanodevice applications. Four basic methods have been employed thus far to fabricate heterogeneous 1D nanostructures: nanolithography, direct chemical reaction, template-directed electroplating, and vapor-based methods. A practical nanofabrication technique to produce heterogeneous nanostructures with arbitrary materials must meet the following criteria: (1) The ability to fabricate heterogeneous nanostructures with arbitrarily selected materials; (2) The ability to control the dimensions and uniformity of the heterogeneous nanostructures; (3) The ability to control the alignment of the heterogeneous nanostructures; (4) The ability to control the interfacial properties of the heterogeneous nanostructures. Here, we demonstrate a simple but versatile method to fabricate three-dimensional heterogeneous nanorod structures by multilayer dynamic shadowing growth (DSG). DSG is based on geometric shadowing effect and substrate rotation in a physical vapor deposition system. By programming the azimuthal rotation of the substrate, aligned nanorod arrays with different shapes can be fabricated. By changing the source materials during the deposition, we demonstrate that complicated heterostructured nanorod arrays, such as Si/Ni multilayer nanosprings,[1] can be easily produced, and they exhibit particular magnetic anisotropic behavior. We also use the DSG technique to design catalytic nanomotors[2] with different geometries that are capable of performing different and desired motions in a fuel solution. Using the shadowing effect, a thin catalyst layer can be coated asymmetrically on the side of a nanorod backbone. Catalytic nanomotors such as rotary Si/Pt nanorods, rotary L-shaped Si/Pt and Si/Ag nanorods, and rolling Si/Ag nanosprings, have been fabricated, and their autonomous motions have been demonstrated in a diluted H_2O_2 solution. We observed that the catalytic decomposition of H_2O_2 on the surface of catalyst generated a propelling force to push the nanorod from the catalyst side with an estimated driving force on the order of 10^{-13} - 10^{-14} N. This fabrication method reveals an optimistic step toward designing integrated nanomachines.

[1] Y.-P. He, J.-X. Fu, Y. Zhang, Y.-P. Zhao, L.-J. Zhang, A.-L. Xia, and J.-W. Cai, Multilayered Si/Ni Nanosprings and Their Magnetic Properties, small 2007, 3(1), 153-160.

[2] Y.-P. He, J.-S. Wu, and Y.-P Zhao, Designing Catalytic Nanomotors by Dynamic Shadowing Growth, Nano Lett. 2007, 7(5), 1369-1375.

2:00pm **TF-WeA2 Effects of Steering and Shadowing in Epitaxial Growth**, ***J.G. Amar***, University of Toledo **INVITED**

While a variety of surface relaxation processes are usually assumed to determine the surface morphology in epitaxial growth, the deposition process can also play an important role. For example, in the case of unstable metal epitaxial growth, the steering of depositing atoms due to short-range (SR) and long-range (LR) attraction can significantly enhance the surface roughness and mound angle,[1] while for large angles of incidence shadowing can also play an important role. In particular, in recent experiments on grazing incidence Cu/Cu(100) growth,[2] a series of morphological transitions was observed as the angle between the beam and substrate normal was increased, from symmetric to asymmetric mounds at moderate deposition angles, to asymmetric ripples oriented perpendicular to the beam at larger deposition angles, and finally to symmetric pyramids with (111) facets at very large angles. Here we discuss the roles of steering and shadowing in determining the observed surface morphology.[3] We first present results obtained using a simplified model which includes the effects of shadowing but not SR and LR attraction. Our results indicate that many of the features observed in Cu(100) growth, including the existence of a transition from asymmetric mounds to ripples, can be explained primarily by geometrical effects. We also show that the formation of (111) facets is crucial to the development of ripples at large angles of incidence. A second transition to 'rods' with (111) facets oriented parallel to the beam is also found at high deposition angles and film thicknesses. When steering due to SR and LR attraction is included, we find two main effects. In the multilayer regime 'flux-focusing' due to attraction tends to enhance the anisotropy and reduce the critical thickness for the ripple transition. In contrast, near the transition from ripples to rods, sideways attraction tends to stabilize the formation of symmetric pyramids as is observed experimentally. The scaling of the surface roughness and anisotropy as a function of film thickness and deposition angle and the effects of growth temperature and surface relaxation processes such as edge-diffusion on the surface morphology will also be discussed.

[1] J. Yu and J. G. Amar, Phys. Rev. Lett. 89, 286103 (2002).

[2] S. van Dijken et al, Phys. Rev. B 61, 14047 (2000).

[3] Y. Shim and J.G. Amar, Phys. Rev. Lett. 98, 046103 (2007).

2:40pm **TF-WeA4 Mechanisms of Thin Film Growth under Shadowing and Re-Emission Effects**, ***T. Karabacak***, University of Arkansas at Little Rock **INVITED**

Over the last decades, there has been a continuing interest on the mechanisms of the dynamic growth front morphology of thin films. Several competing mechanisms such as noise, surface diffusion, and shadowing have been well known to play roles in the evolution of surface roughness. Based on these effects, various growth models have been developed within the frame work of dynamic scaling theory in order to predict the evolution of thin film morphology. However, many experimentally obtained surfaces have been realized to be much rougher or smoother than the predictions of these models. Especially in processes where the shadowing effect is important due to the existence of obliquely incident particles (such as in sputter deposition, chemical vapor deposition, and plasma etching), the morphological evolution was smoother for deposition, while it was rougher for etched surfaces compared to the expected effect of shadowing. A recently recognized "re-emission" effect that originates from the non-unity sticking probability of incident particles offers a better understanding of morphological growth process. Non-sticking re-emitted particles can lead to a rough surface during etching and a smooth surface during deposition. It is shown that competing effects of shadowing and re-emission can predict many of the experimental results reported in the literature. It is also proposed that shadowing and re-emission effects can lead to a novel "universality class" of dynamic scaling behavior of the surface roughness.

4:00pm **TF-WeA8 Ripple Growth and - Orientation during Grazing Incidence Deposition**, ***H. Wormeester***, *F.L.W. Rabbering, F.G. Stoian, R. Gastel, B. Poelsema*, University of Twente, The Netherlands

Oblique incidence deposition is widely used for the preparation of anisotropic structures in thin films with interesting magnetic or optical properties. We have studied the consequences of oblique incidence deposition for the morphology of the growth-front for a "prototypical" system Cu/Cu(001). According to previous electron diffraction measurements, deposition at grazing incidence leads to the evolution of ripples, oriented perpendicular to the plane of incidence of the atom beam. Here we present new experimental results, obtained with high resolution low energy electron diffraction and STM, for various stages in the formation of the ripples. At grazing incidence, experiments indeed show that initially the ripples are oriented perpendicular to the plane of incidence of the atom beam. At more progressed stages of growth and at very grazing incidence deposition experiments show a deviation from the ripple formation. The ripple formation has also been studied with kMC simulations, which support (or actually predicted) experimentally observed changes in ripple formation at later stages in growth. The relevant activation barriers for intra- and interlayer diffusion processes in these simulations have been tuned to describe quantitatively(!) experimentally observed morphologies in a wide range of temperatures (150-300 K) and coverages (up to 40 ML). An essential role is played by both long and short range attractive interactions between the incoming particle and the substrate. The kMC simulations show a change in ripple orientation from perpendicular to the plane of incidence to parallel to this plane around a coverage of 40 ML at a temperature of 250 K for a deposition angle of 80°. At 230K this orientation transition has been found to occur at a much earlier stage in growth. At more grazing incidence deposition only ripples parallel to the plane of incidence have been found to develop and no change in orientation has been seen for smaller deposition angles. This orientation change is related to the very strong roughening of the growth front for grazing incidence growth and the corresponding heterogeneity of incident flux.

4:20pm **TF-WeA9 Biaxial Texture of Titanium Nitride Thin Films Deposited by Off-normal Incidence Magnetron Sputtering**, ***D. Deniz***, *J.M.E. Harper*, University of New Hampshire

We studied the development of crystallographic texture in titanium nitride films deposited by off-normal incidence reactive magnetron sputtering at room temperature. For a deposition angle of 40 degrees from normal, we obtained strongly oriented biaxial textures for a range of deposition conditions using both direct current (DC) and radio frequency (RF) sputtering. Texture measurements were performed by x-ray pole figure analysis of the 111 and the 002 orientations. Typically, we find that the 111 orientation is close to the substrate normal and the 002 orientation is close to the direction of the deposition source, showing substantial in-plane alignment. For example, TiN deposited by DC sputtering at 5% $N_2/(Ar+N_2)$ flow ratio and 2.2 mTorr total pressure showed 111 planes perpendicular to the substrate and 002 planes tilted 55 degrees from the substrate normal and facing the source. However, TiN deposited by DC sputtering at 2% $N_2/(Ar+N_2)$ flow ratio and 1 mTorr total pressure showed 111 planes tilted 18 degrees from the substrate normal but away from the source and 200 planes tilted 35 degrees from the substrate normal towards the source. The strength of biaxial texture decreases as the $N_2/(Ar+N_2)$ flow ratio is increased up to 20%. These results suggest a competition between texture mechanisms related to the substrate normal and related to the deposition direction.

4:40pm **TF-WeA10 Zeno Effect and Step Edge Barrier in Organic Thin Films**, ***C. Teichert***, *G. Hlawacek*, University of Leoben, Austria, *P. Frank, A. Winkler*, Graz University of Technology, Austria

Organic Semiconductors start to enter the market of consumer products as light emitting diodes, solar cells and thin film transistors. For the growth of reliable high quality devices a profound understanding of the processes related to formation of organic thin films is necessary. Here, we present an AFM study on the growth of para-sexiphenyl on a sputtered mica(001) surface. Para-sexiphenyl is a member of the group of small conjugated molecules with a high mobility[1] and the ability to emit blue light.[2] The morphology is characterized by the formation of mounds formed by upright standing molecules. Needle growth competes with the formation of the mounds. However, the characteristic layer distribution of the mounds can be fitted by a Poisson distribution. This shape is related to the Zeno effect known from inorganic epitaxy.[3] The mound shape for different film thicknesses has been analysed. Furthermore, statistical roughness parameters such as rms roughness σ, hurst parameter α and mound separation λ have been evaluated. Growth exponent β and dynamic exponent $1/z$ can be calculated and agree with the predictions made by the Zeno model. The mound separation λ and the size of the top terrace allow estimating the size of the Ehrlich Schwoebel barrier responsible for the cross-sectional shape of the mounds. Work has been supported by Austrian Science Fund (FWF) National Research Network "Interface controlled and Functionalised Organic Films" (S9707-N08).

[1] T. Birendra Singh, G. Hernandez-Sosa, H. Neugebauer, A. Andreev, H. Sitter, N.S. Sariciftci, Phys. Status Solidi B, 243, (2006) 3329.

[2] A. Kadashchuk, A. Andreev, H. Sitter, N.S. Sariciftci, Y. Skryshevski, Y. Piryatinski, I. Blonsky, D. Meissner, Adv. Funct. Mater. 14 (2004) 970.

[3] T. Michely and J. Krug; Islands, Mounds and Atoms (Springer, Berlin 2004).

Authors Index

Bold page numbers indicate the presenter