Study of Electro- and Magneto-Mechanical Nano-Assamblies

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The ability to simply and controllably grow three-dimensional nanostructures is necessary for the full realization of future nano-scale devices. Advanced lithography techniques such as electron-beam or X-ray lithography are time consuming and prohibitively expensive for large area substrates. The oblique angle deposition (OAD) technique has been demonstrated to have the capability of efficiently growing three-dimensional nanostructures. Some of these nanostructures such as nanosprings can not be fabricate using electron-beam or X-ray lithography. The convenient application of the OAD technique on large area substrates may assist in the wider utilization of nanostructure based devices. The goal of our interdisciplinary project is to explore and develop the OAD and to characterize the physical properties (mechanical, electrical, thermal, etc.) of the nanostructures grown using this technique.

The nanostructures that grow during OAD are physically self-assembled structures that form due to the shadowing effect. When an atomic vapor flux is incident at an oblique angle to the substrate normal, surface height irregularities lead to the shadowing of lower lying areas. Due to the lack of deposition in the shadowed areas these nanostructures are extremely porous and can have surface area to mass ratios as high as ~50m^2/g [2]. When a substrate is patterned with controlled surface "irregularities" the result is the formation of regularly spaced nanostructures (see Fig. 1 b and c). The isolated nature of nanostructures grown using templated substrates (see Fig. 1a) allows the direct measurement of the physical properties of large numbers of individual nanostructures using scanning probe techniques such as AFM and STM.

1) Growth

One of the challenges in the growth of 3D nanostructures on a templated substrate with regular arrays of seeds is that it gives rise to a phenomenon referred to as 'fan-out' (see Fig. 1b) growth in that the size of the nanostructures overgrows along the direction perpendicular to the incident

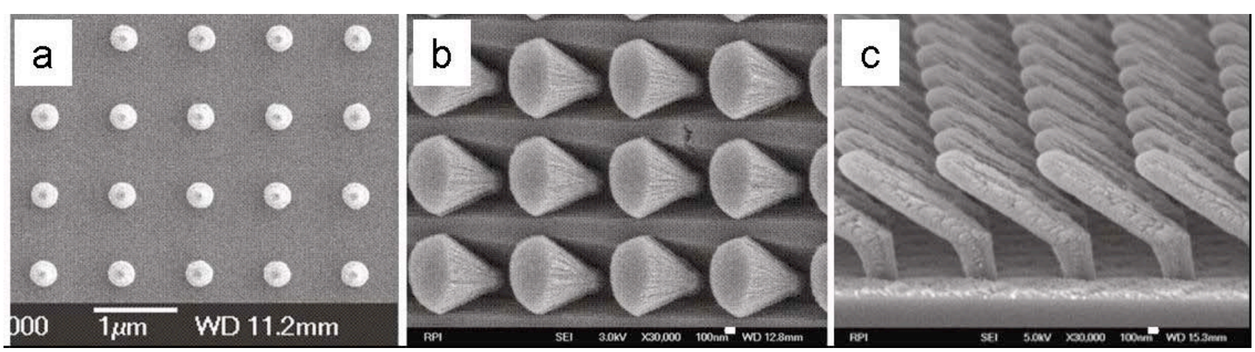

Fig.1 (a) W post template (b) Si rod growth without swing (Scale bar 100nm) (c) Si rod growth with swing (Scale bar 100nm) deposition flux. The net result is that the size of the nanostructures cannot be controlled as they grow. Recently we have employed a back-forth substrate swing rotation method [3]to overcome the 'fan-out' growth (see Fig. 1c).

2) Enhanced photo-emission

We have characterized [4] the photo-emission behavior of nanostructure films (specifically Ru, Pt, and C nanorod films) and observed a ~15-fold enhancement (see Fig. 2b) in photo induced current for a slanted Ru nanorod array (nanorods tilted at 40^0 from the substrate normal) compared to a planar Ru film. We believe the improved performance is due to two effects. We believe that the improved performance originates from two factors- (1) increased surface area of the nanorods that enhances the photon-collection probability and (2) single-crystal nature of the nanorods that increases the electron escape probability due to the absence of grain boundaries. These results show that nano-structured surfaces can be engineered to significantly improve performance in a variety of device applications such as photo-detectors, photon counters and photo-multiplier tubes. Photo-multipliers are of great relevance in all detectors based on scintillating materials. They consist of a photo-cathode (photons are converted into electrons, making use of the photoelectric effect), a multiplier chain (strings of successive electron absorbers with enhanced secondary emission, called dynodes), and an anode that collects the resulting current. If the number of electrons emitted from the photo-cathode and each of the dynodes is increased 15-fold then the overall amplification can be improved by several orders of magnitude. Such ultra-sensitive nano-structured photo-multipliers will have a strong impact in a variety of disciplines such as fluorescence spectroscopy used to detect enzymes and biological/chemical tracers, chemi-luminescence, bio-luminescence detection, particle/high energy physics, radiation physics, forensics, high speed photography, gene chip scanners and related medical diagnostic applications.

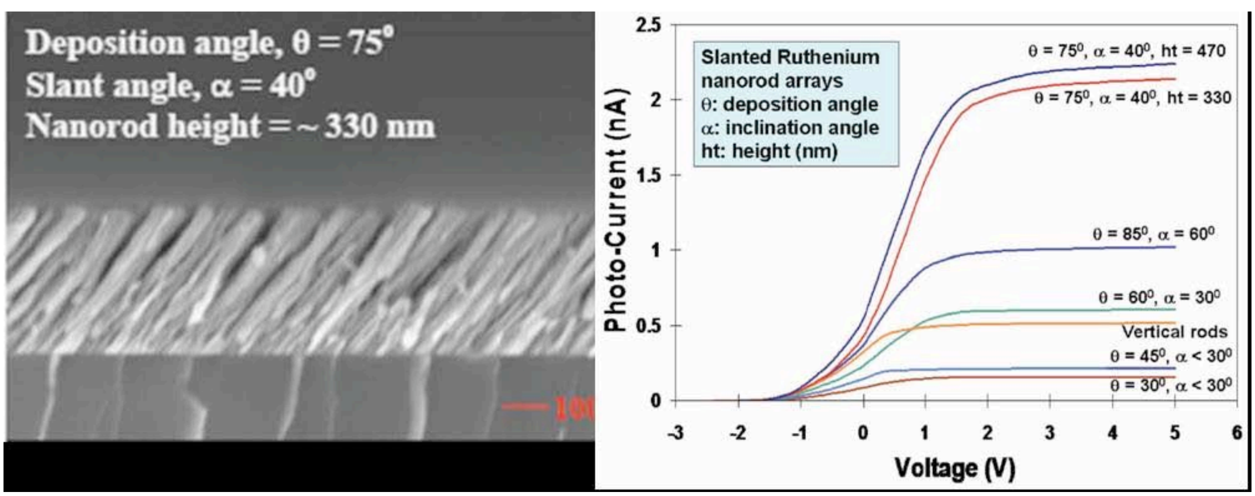

Fig.2 From left to right (a) A cross-sectional SEM image of Ru slanted nanorods with an oblique deposition angle of $\theta=75^0$ with a tilting angle (α) of 40^0 (b) Measured I-V curves from the photoelectric effect for different slanted nanorod samples. The saturation of the photo induced current for the 480 nm slanted rods with $\theta=75^0$ is over an order of magnitude (>1000%) larger than that for a planar Ru film (not shown, ~0.15 nA).

3) Co/Cu Multi-Layers MR (magneto-resistance)

We have fabricated and studied the magneto-conductance behavior of multi-layer Co/Cu nanorods (see Fig. 3a and b). The Co and Cu were sequentially deposited on a Si(100) substrate in a high vacuum thermal evaporator with an oblique incident angle of ~85°. Once grown the nanorods were studied *ex-situ*, a non-magnetic STM was built and used to make an electrical contact with the multi-layer nanorod sample. The resistance of the nanorod sample was monitored while an oscillatory magnetic field was applied to the sample. The resulting resistance versus magnetic field (MR= ~1%) data is shown in Fig. 3c. The Co/Cu multi-layer nanorods have potential applications in spintronics and ultra-high density data storage devices.

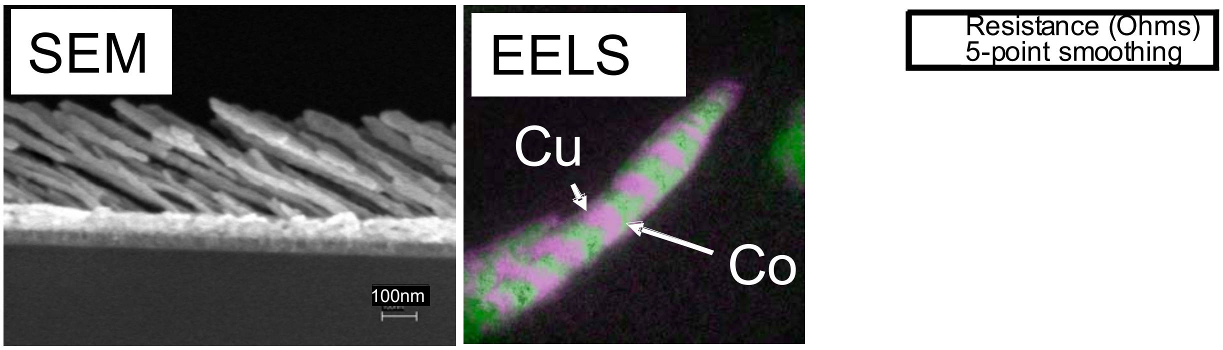

Fig.3 From left to right (a) A cross-sectional SEM image of Co/Cu multi-layer nanorods (b) An electron energy loss spectroscopy (EELS) image of a Co/Cu multilayer nanorod (c) MR (magneto-resistance) measurement on the Co/Cu multilayer nanorod sample

References

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