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Ta/Cu_{1-x} Nd_x/NiFe/Ta Layers Characterized Using TEM/Microanalysis Techniques

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Magnetic and non-magnetic bilayer such as Permalloy (Py)\Cu is the basic unit in spintronic devices. To tune spin pumping effect of the bilayer system and enhance magnetic damping coefficient of Py, we fabricated Py\$Cu_{1-x}Nd_x$ bilayer films with capping (2nm) and buffer (5nm) layers of Ta deposited on silicon substrates at room temperature by magnetron sputtering. The Py thickness is about 10nm and $Cu_{1-x}Nd_x$ film thickness could be controlled from a couple of nm to a few tens of nm. There are several practical questions:
1) Based on the fact that Cu has almost no solubility in Nd, it is interesting to understand the microstructure of the $Cu_{1-x}Nd_x$ film.
2) XRD patterns do not show any peaks associated with Cu when $x > 0$. Is the $Cu_{1-x}Nd_x$ film amorphous?
3) The deposition rate was normally calibrated using pure materials. How accurate is the film thickness? When Cu and Nd were sputtered together, how could the film deposition rate be affected?
4) Ta buffer layer is amorphous, is there any effect of the buffer layer on Py microstructure?

These questions may be answered by using S/TEM high-resolution imaging techniques together with micro/nanoanalysis such as EDS and EELS.

As an example, Figure 1a shows a cross-sectional HAADF STEM image of Ta/$Cu_{0.65}Nd_{0.35}$/NiFe/Ta layers grown on the Si (100) substrate, where the image contrast is dependent on atomic number and the areas with heavier elements have stronger signal. This cross-sectional TEM specimen was made by using a Tescan SEM/FIB system. Figures 1b-1f display elemental maps. The distributions of Fe, Ni and Nd elements are clearly seen in their maps. However, the Ta and Cu maps are misleading. This is because the characteristic X-ray energies of Cu K and Ta L are very close to each other and the commercial EDS software cannot show much different signals in these maps. Additional analysis is needed to identify Cu and Ta areas. EDS point analysis may reveal different features of Ta and Cu in their spectra. Deconvolution technique may be further used to show correct Cu and Ta maps, separately.

Figure 2 is the bright-field STEM lattice image of Ta\Py layers, where the enlargement of a local area is showed in the inset. The Ta layer is amorphous, but Py layer has a strong <111> texture. Figure 3 is the bright-field STEM lattice image of the $Cu_{0.65}Nd_{0.35}$ layer. This layer contains not only amorphous phase but also nanocrystals. After magnification calibration using the Si lattice fringes, the interplanar spacing of these nanocrystals can be determined quite accurately, but these spacings are not consistent with the crystal structure of Cu2Nd. We are going to explore more areas with 2-dimensional lattice images in order to fully determine the structure and understand the forming mechanism of the film [1].

References:

[1] The Ta/$Cu_{1-x}Nd_x$/NiFe/Ta films were fabricated at Southeast University. The authors would acknowledge the use of IMRI facilities at UCI for the FIB and TEM work.

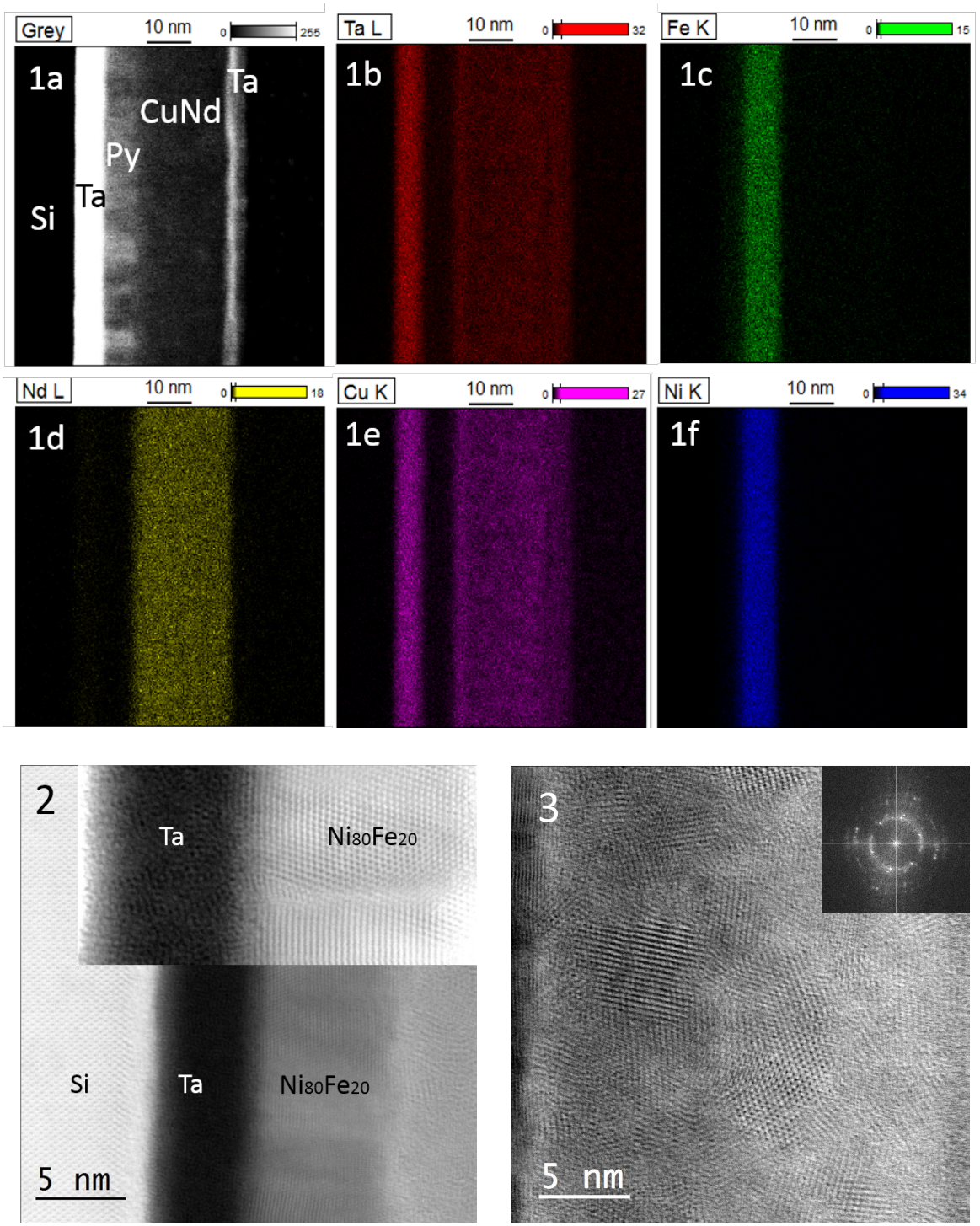

Figure 1. a) Cross-sectional HAADF STEM image of Ta/$Cu_{0.65}$ $Nd_{0.35}$/NiFe/Ta layers deposited on Si (100) substrate. b)-f) are elemental maps of Ta, Fe, Nd, Cu and Ni, respectively.

Figure 2. Bright-field STEM image of the Py/Ta layers on the Si substrate, where the inset is the enlargement of Py and Ta layers.

Figure 3. Bright-field STEM image of the $Cu_{0.65}$ $Nd_{0.35}$ layer and related fast Fourier transformation pattern (inset).

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