Cu Metallic Quantum Well States on Cu/Ni/Cu(100) and Cu/Fe/Cu(100)

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Ultrathin metal films grown epitaxially on metal substrates often exhibit so called metallic quantum well (MQW) states.[1-8] These are electronic states that are confined to the overlayer by reflectivity from projected band gaps in the substrate metal. Even in the absence of such band gaps, significant interface reflectivity can from intense quantum well resonances. Owing to band structure effects, a given MQW state will move to higher energy as the thickness of the overlayer increases. Furthermore, the periodicity with which these states cross the Fermi level is expected to be a function of the overlayer band structure and insensitive to the substrate.

Much of the work on MQW states has concentrated on the behavior of Cu on various transition metal substrates such as Ni and Co, owing to their importance in magnetic multilayers. In the unoccupied electronic states above the Fermi level, the Cu/Ni(100) system is unusual in that the Cu-induced levels disperse downward with increasing film thickness, rather than downward.[9, 10] It was thought that this might be due to strain in the Cu film. To test these ideas, we used photoemission and inverse photoemission to study the occupied and unoccupied overlayer electronic states of the Cu/Ni/Cu(100) system as a function of Cu and Ni thickness.

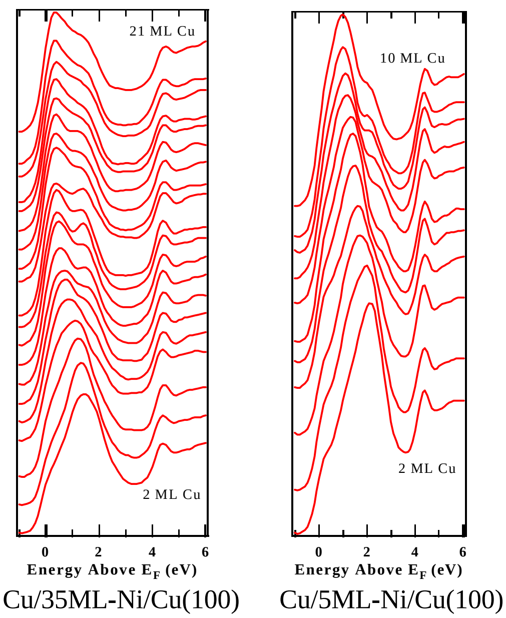


Fig. 1: Downward dispersion of unoccupied Cu states in the Cu/Ni/Cu(100) system.

In Fig. 1 we show inverse photoemission spectra from increasingly thick Cu overlayers on a 35 ML and on a 5 ML film of Ni grown on Cu(100). One can see that the results are qualitatively similar to eachother, and to the Cu/Ni(100) results, in that the Cu-induced states disperse downward as a function of increasing Cu film thickness. There are quantitative differences, however. The states of the Cu films grown on the thinner Ni layer are at higher energy than those on the thicker Ni film. Although it appears that the downward dispersion does not appear to arise from a strain effect, these quantitative differences may. To test this, we measured normal emission photoemission from wedges of Cu grown on two different thickness Ni films on the same Cu(100) substrate. A diagram of the sample geometry is shown in Fig. 2. Two identical Cu wedges were grown on Ni films of 7 ML and 35 ML thicknesses.

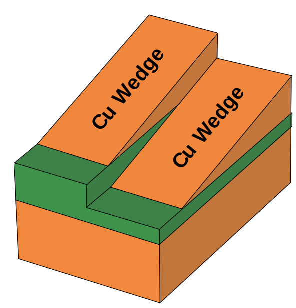
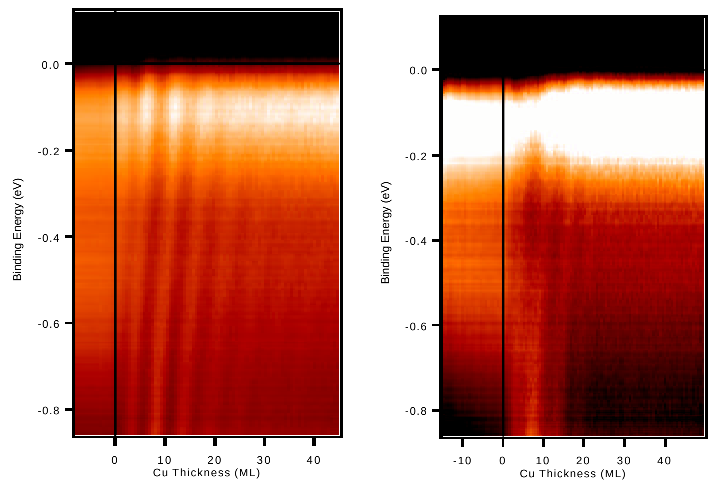


FIG.2: Sample geometry for photoemission studies.

Using the UltraESCA end station of Beamline 7.0.1, we have obtained photoemission data from the Cu/fccNi/Cu(100) system. The sample was prepared by depositing the Ni onto an atomically clean, well-ordered Cu(100) surface. This was followed by deposition of a wedge-shaped Cu film whose thickness ranged from 0 to 40+ ML. Figure 3 show a series of normal emission photoemission data displayed as a 2-dimensional plot of Cu film thickness vs. binding energy. Light colors indicate high intensity and the dark colors low. These peaks are associated with metallic quantum well states in the Cu films. In contrast to the inverse photoemission data, the intensity maxima that move towards the Fermi level as the film thickness increases. Although the MQW states are less pronounced on the thicker Ni film, the period with which these Cu MQW states cross E_F appears are identical. As a change in the Cu lattice constant would change the electronic structure and thus change the periodicity of the Fermi level crossings, these results suggest that there is minimal change in strain in these Cu films. Strain in the Ni, however, may cause this effect. Quantitative structural studies and first principles electronic structure calculations are currently underway to investigate the low energy structures of these systems.



Cu/5ML-Ni/Cu(100) Cu/35ML-Ni/Cu(100)

Fig. 3.: Normal emission from the Cu/Ni/Cu(100) systems as a function of Cu film thickness.

Another important observation is the sharp contrast between the upward dispersion of Cu MQW states below the Fermi level and the downward dispersion of Cu state above E_F. Most likely this difference arises because the Ni *d*-bands terminate about E_F + 0.1 eV. The downward dispersion if the Cu states on Ni is most likely associated with the interaction of the Cu and Ni *sp*-band.

Finally, we have also grown Cu/fccFe/Cu(100) quantum well structures and the exhibit a strong upward dispersion and cross EF with a periodicity that is, within experimental uncertainty, the same as that of the Cu/Ni system.

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