Quantum well states in thin Ag films on Ga/Si(111)-$\sqrt{3}\times\sqrt{3}$

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Ag thin films on semiconductor substrates have been studied for over thirty years due to their electronic structures exhibiting Quantum Well States (QWSs) [1]. QWSs are discrete electronic energy states formed by spatially confining electrons in one dimension, such as in a thin film. They have a parabolic energy dispersion and are of interest both for fundamental physics and potential device applications. In order for a thin film to show well defined QWSs, the film must be as uniform as possible. Growing well-ordered Ag films on Si substrates faces several challenges: such as requiring low temperature (100 K) deposition and avoiding the formation of strain [2]. The semiconducting Ga/Si(111)-$\sqrt{3}\times\sqrt{3}$ surface with its lack of dangling bonds has been shown to be a good candidate to overcome these obstacles [3]. Here we have studied the electronic and geometric structures of Ag thin films on the Ga/Si(111)-$\sqrt{3}\times\sqrt{3}$ surface using angle-resolve photoelectron spectroscopy (ARPES) and scanning tunneling microscopy (STM).

The Ga/Si(111)-$\sqrt{3}\times\sqrt{3}$ was formed by a deposition of 0.4 monolayer (ML) of Ga on a Si(111)-7×7 surface, after annealing of sample at ~580 °C for 2 min. STM measurements have been performed on the Ga/Si(111)-$\sqrt{3}\times\sqrt{3}$ surface as well as on Ag films with thicknesses lower than 5 ML. STM images of the Ga/Si(111)-$\sqrt{3}\times\sqrt{3}$ surface highlight the importance of the annealing method for minimizing surface defects, such as Si substitution atoms. In addition, the STM images provide a means to confirm the Ag film thickness for studies of the electronic structures. Core-level spectroscopy and ARPES measurements using synchrotron radiation have also been carried out on Ag thin films formed on the Ga/Si(111)-$\sqrt{3}\times\sqrt{3}$ surface, with Ag coverages up to 12 ML. ARPES Measurements reveal both fully confined QWSs above the bulk Si *sp* bands as well as resonant states below. Well-defined QWSs can be observed already at a two ML Ag coverage. The curvatures of the QWSs exhibit "kinks" which represent changes in the effective mass (m*), where the QWSs couple with the substrate electronic structures. There are also umklapp-mediated quantized states at then M points of the Si surface Brillouin zone. In-plane effective mass below the Si *sp* band was calculated by parabolic approximation for the QWS, showing an increase of m* with quantum well binding energies. The effective mass also showed a reduction with increased film thicknesses. These results open an opportunity for studying many-body effects on ultra-thin Ag films with well-defined quantum well states.

References:
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