The role of the quantum size effect on the growth of metallic nanostructures

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In the 1990s a novel growth mode was found, which resembles Stranski-Krastanov growth, but is qualitatively different from the classical growth modes in that quantum size effects (QSEs) seem to dominate, leading to non-trivial smooth film growth described as electronic or quantum growth. In this novel growth mode, the growth of thin Pb(111) films has attracted particular interest, since its Fermi wavelength is nearly commensurate to the bilayer atomic spacing and QSE driven growth sometimes persists even over 30 layer thick islands [1]. Another candidate we propose is Bi, a material that is 'hovering' between being a metal and a semiconductor, making electronic effects more pronounced than strain effects. This property makes thin Bi films prime candidates for allotropism and a candidate for electronic growth.

QSEs are usually found on surfaces with a bandgap in the surface projected bulk bands, making a direct coupling between the electrons of the film and the substrate bulk impossible. Examples are semi-conductors such as Si(111) and Ge(111), as well as metals such as Cu(111) and Ag(111), but the substrate of our choice, Ni(111), just misses such a bandgap. We will demonstrate a route, where the intrinsic modification of the electronic properties of the Ni(111) surface by the mere presence of a Bi- or Pb-film may just suffice, to generate a situation with a surface projected bandgap.

We present (I/V-) Low Energy Electron Microscopy (LEEM) and selective area (I/V-) Low Energy Electron Diffraction (μLEED) measurements in combination with modeling and Tensor LEED calculations, illustrating indeed the QSE driven growth for Pb on Ni(111) in comparison to the key examples of QSEs [2,3]. We demonstrate the importance of the QSE on the growth of thin films by showing the influence in thin Bi films, where the QSE determines the thin film structure, density and interlayerdistance, in order to embrace the standing Fermi waves with a wavelength far smaller than in the bulk material [4]. We expect the structures found in the thin bismuth films to be far better conductors than ordinary bismuth, and expect other physical and chemical properties of the newly discovered crystal structures to differ from those in the bulk bismuth as well.

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