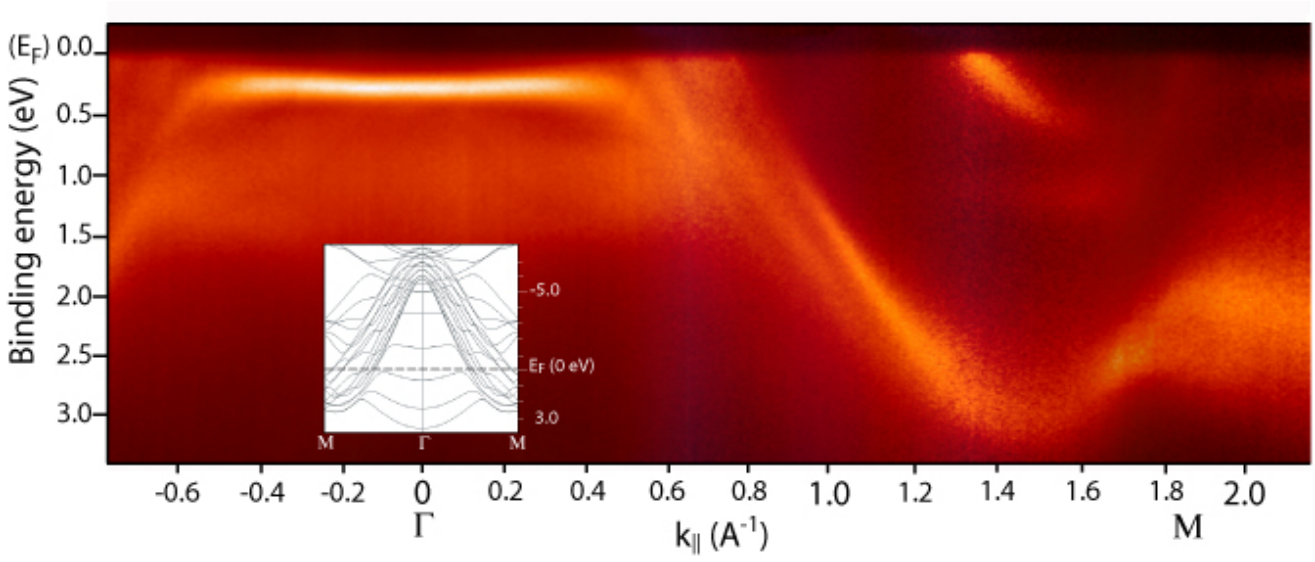
Cross Section through the Brillouin Zone of Pb 2D Quantum Well State Bands

Application Notes

Thin films of Pb on Si(111) have shown a wide variety of exciting physical properties such as interface structure dependent Schottky barrier [1], quantum mechanical stabilized uniform magic heights [2], anomalous optical absorption [3], anisotropic metal-insulator transition [4] and unusual band dispersion [5].

The free electron metal Pb has unexpected properties when it is subjected to a reduction in dimensionality. In very thin films the electronic wave functions have discrete values for the wavevector in the direction perpendicular to the surface and continuous bands of electronic states in the plane of the surface. The coupling of the Si(111)-Pb interface structure and the reduction from a 3D free electron metal to an electron system with a 2D band structure and discrete quantum confined states perpendicular to the surface leads to the richness of physical phenomena in this system.



The image shows the Brillouin Zone of a thin Pb film (~5ML) on a Si(111) substrate. At the centre of the Brillouin Zone (Γ) the bands formed by the Pb $6p_z$ states have an unexpectedly and anomalously large effective mass, while the 2D bands of the Pb $6p_{xy}$ states (crossing the Fermi level at $0.8A^{-1}$) have a free electron behaviour. The inset shows the calculated band structure. This image is a compilation of for images taken with a PHOIBOS 100 analyzer with the 2D-CCD Detector. Data courtesy J.H. Dil, K Horn (Fritz Haber Institut, Berlin) and A.R.H.F. Ettema, (TU Delft).

The photoelectron spectroscopy image of the 2D-bands in a thin Pb film grown on a Si(111)√3x√3 surface taken with a Phoibos 100 analyzer equipped with a 2D-CCD detector unveils the details of the complex electronic structure of the Pb quantum wells on Si(111). The quantum well states that can be associated with the Pb $6p_z$ states are observed at the centre of the Brillouin Zone (Γ). Contrary to the free electron behaviour in the bulk, the effective mass of these bands ranges from $2m_e$ to more than $10m_e$ and for some film thicknesses to a sign reversal of the effective mass. The bands consisting of the Pb $6p_{xy}$ states remain their free electron behaviour, which appears in the strong dispersive bands that cross the Fermi level between Γ and M.

The photoelectron data measured with the Phoibos 100 and a 2D-CCD detector provides direct visual evidence for the electronic effects that was suggested by the STM study on the metal-insulator transition [4] of this system.

References:

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Mode	D	Acceptance Angle	Energy Range
High Angular Dispersion	3.2 mm/°	± 3°	Not yet available
Medium Angular Dispersion	2.2 mm/°	± 4°	Ep × [1 – 200]
Low Angular Dispersion	1.2 mm/°	± 7°	Ep × [0.05 – 30]
Wide Angle Mode	0.5 mm/°	± 13°	Ep × [0.1 – 3]

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