

# SI(111) SURFACES WITH TWO-DIMENSIONAL, METALLIC ELECTRONIC STATES

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Metallic surface states on a semiconducting substrate provide an opportunity for creating low-dimensional electron systems that are de-coupled from the bulk. Surface states near the Fermi level lie in the band gap and cannot hybridize with substrate states. The electron density can be modified by surface doping or by phase transitions at low temperatures. Examples of these two cases are the the Si(111)- $\sqrt{3} \times \sqrt{3}$ -Ag surface and the clean Si(111)- $7 \times 7$  surface.

The Si(111)- $7 \times 7$  surface is one of the most investigated surfaces, and yet the electronic structure near the Fermi level is still controversial. While the  $7 \times 7$  surface is metallic at room temperature [1] there has been evidence for the opening of a Hubbard gap at low temperature from EELS, NMR, and theory [2-4]. A sharp Kondo peak has been proposed to lie at the center of this gap. The reported half-widths of the correlation gap ranges from 40meV to 400meV. Using high-resolution angle-resolved photoemission we find that the Fermi edge shifts by less than 20 meV from 300 K to 20 K. Two adatom bands are observed, an electron-like band starting at 0.2 eV below to  $E_F$  and a partially-occupied hole band straddling  $E_F$ . The band topology is similar to that obtained from local density calculations in [4] and consistent with an occupation of 5 electrons per  $7 \times 7$  unit cell, assuming double degeneracy for the upper band as in [4]. These observations suggest an identification of the lower Hubbard band with the lower photoemission band and the Kondo peak with the upper band at  $E_F$ .

The semiconducting Si(111)- $\sqrt{3} \times \sqrt{3}$ -Ag surface can be doped by adsorption of additional Ag and Au atoms [5,6]. Very high levels of doping can be achieved (0.0015–0.086 electrons per  $1 \times 1$  unit cell), such that this surface degenerates into a metal. The doping alters the band structure of the surface state and causes the rigid-band model to break down. The parabolic-band approximation breaks down as well. These observations shed light on the mechanism of doping at extreme levels.

- [1] U. Backes and H. Ibach, Solid State Commun. **40**, 575 (1981).
- [2] J.E. Demuth, B. N. J. Persson, and A. J. Schell-Sorokin, Phys. Rev. Lett. **51**, 2214 (1983); B. N. J. Persson and J. E. Demuth, Phys. Rev. B **30**, 5968 (1984).
- [3] R. Schillinger, C. Bromberger, H. J. Jänsch, H. Kleine, O. Köhlert, C. Weindel, and D. Fick, Phys. Rev. B **72**, 115314 (2005).
- [4] J. Ortega, F. Flores, and A. L. Yeyati, Phys. Rev. B **58**, 4584 (1998).
- [5] Y. Nakajima, S. Takeda, T. Nagao, S. Hasegawa, and X. Tong, Phys. Rev. B **56**, 6782 (1997).
- [6] J. N. Crain, M. C. Gallagher, J. L. McChesney, M. Bissen, and F. J. Himpsel, Phys. Rev. B **72**, 045312 (2005).