Low-dimensional electronic states on vicinal Cu(111)

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One of the concerns in material research is the interdependence between the electronic structure and geometric nanostructuring. In this context we are investigating the influence of a regular step array, representing a defect nanostructure, on a surface electronic feature, the p_z-like state of Cu(111). The occupied part of the dispersion of this surface state was observed initially by angular resolved photoemission (ARPES) [1]. Also in real space, by scanning tunneling microscopy (STM), a wave-vector-resolved measurement of the band, including the unoccupied part, was achieved [2].
For the above described purpose we prepared a series of samples with surfaces of varying terrace width and step type. The terrace orientation is [111], the step direction is $[\bar{1}10]$. Thus the step edges have either exclusively (100)-like (open) or (111)-like (closed) minifacets (see Fig. 1 left). The regularity of the step arrays was checked in advance by STM (see Fig 1 right) [3]. Such equidistant arrangements are due to the repulsive step-step interaction from the line dipoles and the elastic fields. The identification of the samples with regard to the minifacet type at the step was made by Laue diffraction, low energy electron diffraction (LEED) and by atomically resolved STM topographs.

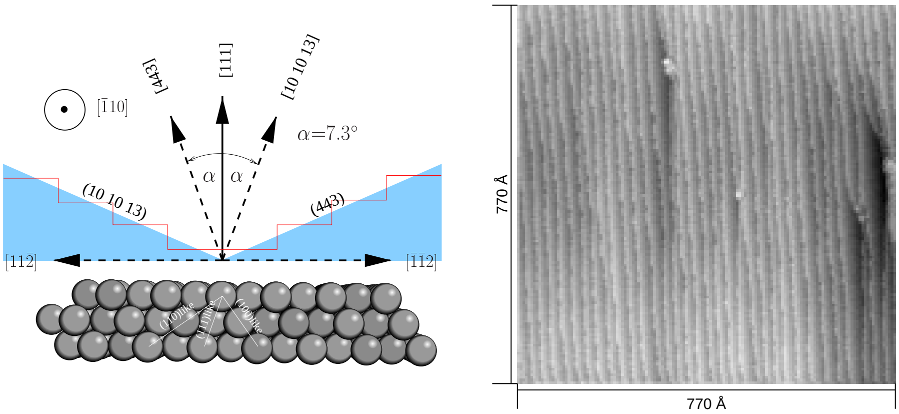


Figure 1: Surface structure. Left: model of the 7.3° sample pair. Right: STM topograph of the 5° surface with open minifacet type at the steps. The frizzy appearance of the step edges is caused by the relative high step mobility on Cu surfaces at room temperature.

The photoemission experiments were performed at the F2.2 beamline, which offers sample preparation, LEED, and electron energy analysis. The dispersion relations of the 9° open, 9° closed, 5° open, 5° closed and a flat (111) sample have been measured. The terrace widths on these samples are 13Å, 13Å, 24Å, 24Å and $>$ 100Å, respectively. The detection geometry was selected to have p-polarization, i.e. 15° grazing incidence either perpendicular or parallel to the steps and the analyzer angle was varied in the plane of the light. The signal was normalized to the photon flux measured at the entrance of the chamber by a Au grid. Three different excitation energies (10eV, 13eV, 22eV) have been chosen.

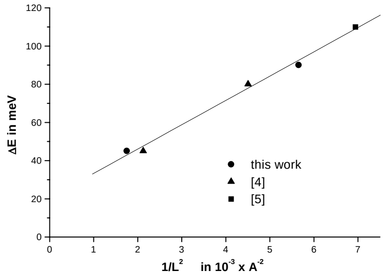
We have measured several different features of the surface states, such as their intensity dependence with miscut angle; dispersion, effective mass and minimum binding energy of the surface state; energetic width as a function the different experimental parameters, etc. This information will allow us to determine a complete picture on the properties of the surface states and their origin.

Here we briefly describe two of the changes we observe in the dispersions of the stepped surfaces: The effective mass of the stepped surfaces is increased compared to the flat surface, though the situation we found is still far away from completely reflecting steps when the effective mass would become infinte. The existence of dispersion contrasts with recent STM results [6], indicating that scattering at the steps is different when the density of steps is very high. This is probably due to the fact that surface states on a vicinal surface are always referred to a different surface plane, i.e. the optical surface.

We observe a slightly lowered binding energy at the center of the dispersion for the stepped surfaces. This can be explained by partial confinement. Assuming that, in our case, absorption (inelastic scattering) at the step edge only influences surface state lifetime, it is possible to calculate, within a simple one-dimensional approximation [4], the transmission coefficient across the step barrier. This kind of analysis yields that the transmission increases with decreasing terrace width (see Table 1). Fig. 2 compares the energy shifts obtained by different groups and shows the variation with the terrace width.

Energies at the center of the band E_0 and barrier transmissions $|T|^2$. The calculation is according to [4]. Here the effective mass has entered. L labels the terrace width. For comparison literature values for large terraces are given [1,6].

L(Å)	13		24		large
step facet	closed	open	closed	open	unknown
E_0(eV)	-0.31	-0.31	-0.35	-0.35	-0.39
$\|T\|^2$	0.53	0.56	0.25	0.34	≈0



Comparison of the energy shifts of the bottom of the band. A shift of 0meV would correspond to -39meV.

We did not find the backfolding of the band at the *new* zone edge of the step array, though this is expected also for weak barriers. A disturbing factor could be the temperature which limits the step regularity. Also a certain life time and coherence length is necessary to be able to observe a interference effect of the surface electrons. Further, slight contaminations could destroy the effect by pinning few steps together.

This work was supported by the TMR-Contract ERBFMGECT950059 of the European Union.

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