Debate over dispersion direction in a Tomonaga–Luttinger-liquid system

To the Editor — One-dimensional (1D) metals show unique characteristics as a Tomonaga–Luttinger liquid (TLL). Blumenstein *et al.*[1] claimed recently that the density of states at Au-induced chains on a Ge(001) surface exhibits a power-law behaviour that is characteristic to a TLL on the basis of their measurements by scanning tunnelling spectroscopy and angle-resolved photoemission spectroscopy (ARPES). In this Correspondence, we present the following three pieces of evidence from ARPES[2,3] and scanning tunnelling microscopy[4] against the presence of a 1D metal in the direction of the Au-induced chain.

(1) Our recent ARPES study for a single-domain surface[3] demonstrated that the observed metallic surface band[1,2,5,6,7] disperses strongly in the direction perpendicular to the Au-induced chain.

(2) The ARPES results[2,3] indicated that the shape of the metallic band is 2D and anisotropic.

(3) An eightfold charge modulation along the Au-induced chain was observed by scanning tunnelling microscopy[4] in the bias voltage range where the surface metallic band exists.

It is possible that the quasi-1D band shape close to the Fermi energy in the direction perpendicular to the chain gives the observed TLL-like behaviour[1] of the density of states in a limited energy range. ❐

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Blumenstein *et al.* reply — In their Correspondence, Nakatsuji *et al.* claim that the conduction path at the surface would be oriented perpendicular to the nanowire direction. They refer to three arguments: (1) the band dispersion in angle-resolved photoemission spectroscopy (ARPES) being allegedly stronger perpendicular to the chains; (2) the surface state being increasingly two-dimensional (2D) and anisotropic away from the Fermi energy; and (3) an eightfold superstructure existing on the nanowires. Although we welcome an independent view on this interesting system, we do not arrive at the same conclusions, based on our own results.

(1) The previous study by Nakatsuji *et al.*[1] is performed on a vicinal surface with a domain imbalance, which also shows large step bunches. Their ARPES signal is not sufficient to yield a band dispersion in both the first and the second Brillouin zone. Based on second derivative spectra from the third zone, Nakatsuji *et al.* conclude that the 1D electron path lies perpendicular to the chains. However, our scanning tunnelling microscopy investigations, including mapping of the density of states, clearly show a situation with seamlessly conducting 1D filaments oriented in the chain direction, not interrupted by insulating sections and without cross-links between wires[2,3].

(2) The nearly perfect 1D character of the Fermi surface was shown by us[4]. A lesser anisotropy towards higher binding energies of the surface state does not affect the 1D character of conduction electrons at the chemical potential. Moreover, this is not a relevant argument for the discussion of the orientation of the conduction path.

(3) The eightfold superstructure, which is completely described by us[5], is also not applicable to the current discussion as the symmetry of the Fermi surface evidently does not show such periodicity[4]. Therefore the conduction electron system is clearly decoupled from this superstructure.

To conclude, all considerations brought forward in the Correspondence by Nakatsuji *et al.*, leave our results[2] on the Tomonaga–Luttinger liquid in the Au/Ge(001) nanowires undisputed. ❐

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