LATERAL ENGINEERING OF SURFACE STATES: TOWARDS SURFACE STATE NANOELECTRONICS

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The search for information carriers that can be manipulated faster, and consequently at smaller scales, is rapidly evolving from electrons and microelectronics towards photons and photonics. The latter can couple to collective excitations on metallic surfaces known as plasmons that are controllable by surface features on the scale of the wavelength, typically in the order of a fraction of the micron. In this work we demonstrate that electronic surface states on metal surfaces share some of the advantages of plasmons, while their in-plane wavelength is of the order of a few nanometers and their expected response time is faster than the femtosecond. By analogy to plasmonics, we can prove a new concept of surface-state nanoelectronics, where the flow of signal carriers (surface states) can be molded by structures such as steps and nanostructure arrays.

Periodically structured surfaces illustrate the possibilities of using plasmons by designing plasmonic band structures, including guiding through channels open in the two-dimensional structures at gap energies [1]. Plasmons on flat surfaces are governed by the wave equation:

$$(\nabla^2 + k^2)\phi = 0$$

where k is the momentum parallel to the surface, and they are scattered by surface features to yield plasmonic bands in periodic structures [1]. Surface states on noble metals respond to the same wave equation and it is only the wavelength that is different with respect to plasmons as far as the one-particle picture relevant in this context is concerned. Plasmons display wavelengths in the range of the micron in practical applications [1], whereas surface states near the Fermi level have a wavelength of 5 nm in Au(111) and range in the same order in other noble metal surfaces. Therefore, the capability of surface plasmons to carry and process information can be imitated by surface states, only that on a much shorter length scale and with faster response times.

Surface states can be tailored by means of lateral nanostructures down to the sub-nanometer scale. Our experimental approach utilizes Au(111), Ag(111), and Cu(111) vicinal surfaces with different step orientation and size, as well as noble-metal templates obtained by epitaxy of sub-monolayers and thin noble metal films on top of these surfaces, such that a variety of lateral nanostructures with length scales in the range of 1-15 nm are obtained. A number of examples will be presented and discussed. Their common feature is the presence of monatomic step discontinuities, which behave as repulsive electron barriers of the order of 1 eV.Å strength. As a result, the surface potential is periodically modified, giving rise to a new surface electron superlattice band-structure. As an example, we will show experiments and calculations with two-dimensional, hexagonal and orthogonal arrays of misfit dislocations in Ag/Cu systems.

References:

[1] W. L. Barnes, A. Dereux, and T. W. Ebbesen, Nature **424** (2003) 824.