A NOVEL LOW-ENERGY COLLECTIVE EXCITATION AT METAL SURFACES

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Fifty years after the publication of the pioneering work on surface plasmons by Rufus H. Ritchie[1], a new collective excitation at metal surfaces has been theoretically predicted[2,3,4] and measured using angle-resolved electron energy loss spectroscopy[4]. This new mode has an acoustic (linear) dispersion, different to the $q_{\parallel}^{1/2}$ of a two-dimensional (2D) plasmon.

Nearly 2D metallic systems formed in charge inversion layers and artificial layered materials permit the existence of low-energy collective excitations, called 2D plasmons, which are not found in a three-dimensional (3D) metal. These excitations have caused considerable interest because their low energy allows them to participate in many dynamical processes involving electrons and phonons, and because they might mediate the formation of Cooper pairs in high-transition-temperature superconductors. Metals often support electronic states that are confined to the surface, forming a nearly 2D electron-density layer. However, it was argued that these systems could not support low-energy collective excitations because they would be screened out by the underlying bulk electrons. Rather, metallic surfaces should support only conventional surface plasmons[1]—higher energy modes that depend only on the electron density. Surface plasmons have important applications in microscopy and subwavelength optics, but have no relevance to the low-energy dynamics. Here we show that, in contrast to expectations, a low energy collective excitation mode can be found on bare metal surfaces. The mode has an acoustic (linear) dispersion, different to the $q_{\parallel}^{1/2}$ of a 2D plasmon, and was observed on Be(0001) using angle-resolved electron energy loss spectroscopy. First-principles calculations show that it is caused by the coexistence of a partially occupied quasi-2D surface-state band with the underlying 3D bulk electron continuum and also that the non-local character of the dielectric function prevents it from being screened out by the 3D states. The acoustic plasmon reported here has a very general character and should be present on many metal surfaces. Furthermore, its acoustic dispersion allows the confinement of light on small surface areas and in a broad frequency range, which is relevant for nano-optics and photonics applications.

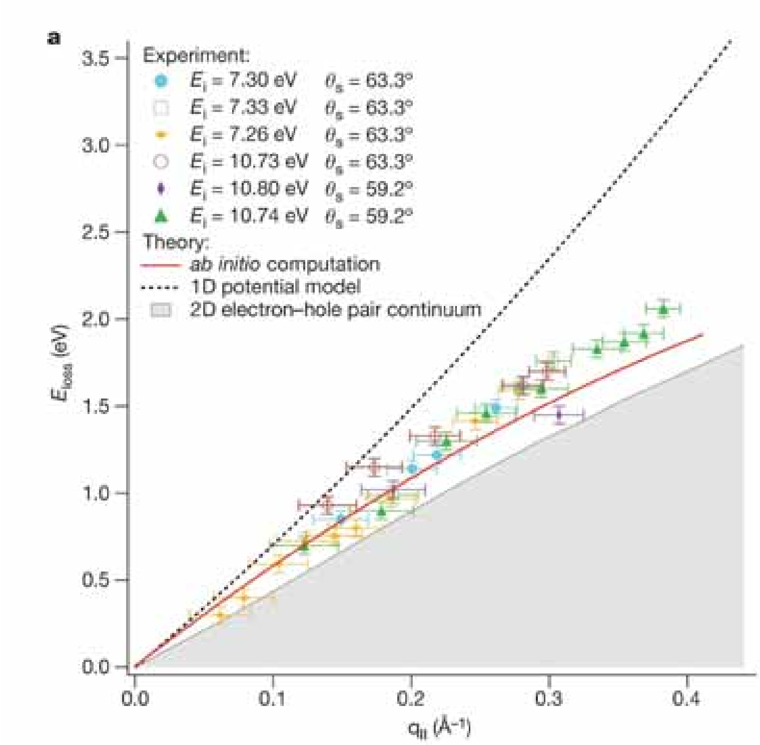

Figure 1. Acoustic surface plasmon energy dispersion. The experimental dispersion was measured at room temperature and various incident electron energies and scattering angles. Energy error bars are due to uncertainties in the multi-peak deconvolution procedure of the EEL spectra, while $q_{||}$ error bars represent the momentum integration window due to the finite angular acceptance of the EEL spectrometer. The theoretical dispersion is indicated by the black dashed line, showing the predicted acoustic surface plasmon dispersion obtained for a free-electron-like surface state, and by the solid red line, which was calculated using an ab initio Be(0001) surface band structure.

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