Surface Plasmons in Conductively Coupled Nanowire Dimers

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Localized surface plasmon resonances (SPR) in nanowires separated by nanogaps are attracting strong interest due to the high electric field enhancement generated at the position of the gap. These structures are called nanowire dimers and are, due to the high field enhancement, interesting e.g. for surface enhanced Raman spectroscopy.[1]

We have synthesized nanowire dimers by electrodeposition of Au-rich/Ag-rich/Au-rich wires in ion-track etched polymer membranes and subsequent dissolution of the Ag segments. Applying this technique we find that not all Ag segments are transformed into a gap but that in some cases two Au segments remain connected by a small metallic junction. These junctions enable current flow between two wires, and modify the plasmonic properties. We have analyzed these differences for dimers with gaps or connections of varying dimensions.[2] Precise knowledge of the SPR energies is crucial for their applications.

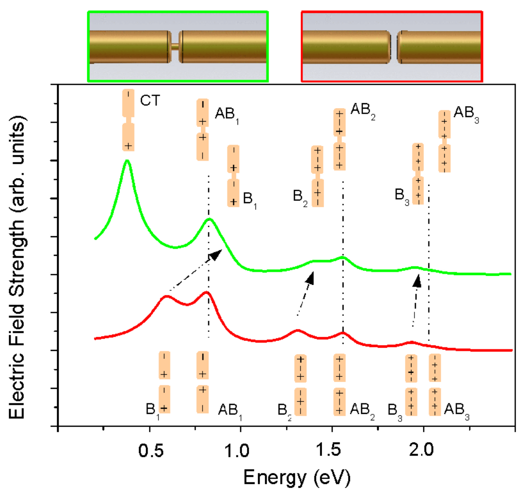

Figure 1: Calculated electric field strength of dimer with gap (red) and with nano-connection (green) vs. excitation energy.#

Figure 1 shows simulations with CST microwave studio[3] of the multipole SPR of two dimers with same length and diameter. The lower (red) spectrum corresponds to a dimer with a gap of 19 nm, while the upper (green) line depicts a spectrum of a connected dimer with junction of length 19 nm and diameter 20 nm. The two spectra show the electric field strength at a distance of 1 nm from an end of the dimers. The nanowire schemes illustrate the surface charge distributions of the corresponding SPR.

The two spectra reveal SPR at varying energies: For the dimer with connection, the so-called charge transfer mode (CT) is excited at low energy. It is not observable in the spectrum of the dimer with gap since in this case current flow between the two wires is prevented. For both dimers three pairs of SPR can be identified. Each pair consists of two modes called bonding mode (B) and antibonding mode (AB), that are close in energy. For the dimer with gap the B-modes are usually excited at lower energies than the corresponding AB-modes.[4] The energies of the three AB-modes are almost identical for the dimer with gap and that with connection. In contrast, the three B-modes are shifted to higher energies for the dimer with connection compared to the one with gap. This blue-shift is caused by a decreasing field strength at the center of the structure with increasing connection diameter.

To compare with simulations, we have performed SPR measurements on dimers. The SPR were excited using the electric field of a monochromated 200 keV electron beam in a TEM and analyzed with an electron spectrometer. The resonances can be identified in the electron spectra as energies of high energy-loss probability.

Figure 2 shows exemplarily a map consisting of 100 spectra measured along a connected dimer. Each horizontal line represents the spectral distribution at the corresponding wire position. The energy increases from 0.25 to 2 eV from left to right. The colors indicate the number of counts. The map confirms our simulation results, revealing the excitation of the CT mode at low energy, and the blue-shift of the B_1-mode compared to the AB_1-mode, which is not observed for dimers with gaps.

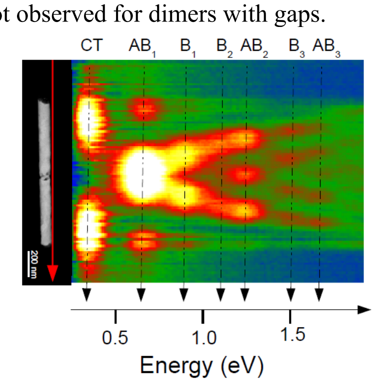

Figure 2: Electron energy-loss map consisting of 100 spectra measured along a dimer with connection (red arrow in TEM image on the left).#

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[1] S. Li et al., Nano Lett. 10 (2010), 1722- 1727.
[2] I. Alber et al., ACS Nano 6 (2012) 9711–9717.
[3] CST AG Darmstadt, www.cst.de.
[4] B. Willingham et al., Appl. Phys. B 28 (2008) 209-216.

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