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Electron Dynamics in Atomic-Scale and Nanoscale Plasmonic Materials

When the size of the object shrinks beyond the micrometer scale and when it reaches down to the nanometer or sub-nanometer scale, novel effects that originate from its smallness and its shape come into play. Atom-scale size effects become especially pronounced in metallic objects, since the Fermi wavelengths of typical metals are in the Ångström range. Plasmons in metal nanostructures show maximum tunability by changing the shape, the size, and thus the dimensionality of the objects. Such feature can be utilized for tailoring optical properties for future nano-photonics/optics devices for information technology as well as high-sensitivity sensors and efficient catalytic materials.

By utilizing bottom-up nanofabrication techniques such as ultrahigh-vacuum MBE growth on template crystal surfaces, we have produced 1D, 2D, and 3D patterned "atomic-scale low- dimensional"metallic nanostructures with precise controlling of its crystallinity and sizes. By "molding"the plasmons into size/shape controlled small objects, we aim at exploring and freely designing the dielectric and optical properties of nanostructures for future applications. For the genuine low-dimensional systems such as atom chains, and atom sheets, nearly no knowledge on plasmon has been available and we experimentally explored these systems in detail. Also, shape-controlled quasi-2D metal-nanoisland array (such as grown by MBE or by the wet-chemistry route) are of special technological importance but not yet studied systematically in a quantitative manner. Their plasmon resonances are related to strong nearfield enhancement, which enables surface enhanced IR absorption (SEIRA) via antenna resonance, and we aim at developing these SEIRA-active device structures for chemo/biosensing applications. Since plasmonic interaction of well-defined specially shaped 3D gold nanostructures with vibration modes may give even higher SEIRA, we also study top-down lithographic structures in order to reach a maximum SEIRA effect.

In this project, we have targeted
1) Atom-scale metallic structures for exploiting the plasmonic excitation and the propagation, confinement, and cavity effects.
2) 3D plasmonic antenna structures for infrared chemo/bio-sensors with attomol sensitivity and quantitative detection.
3) Nanoscale random island films for broadband mid-infrared chemosensing.

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