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Max Planck Institute of Microstructure Physics
Institute of Photonic Technology

Plasmonic Properties of Bimetal Nanoshell Cylinders and Spheres

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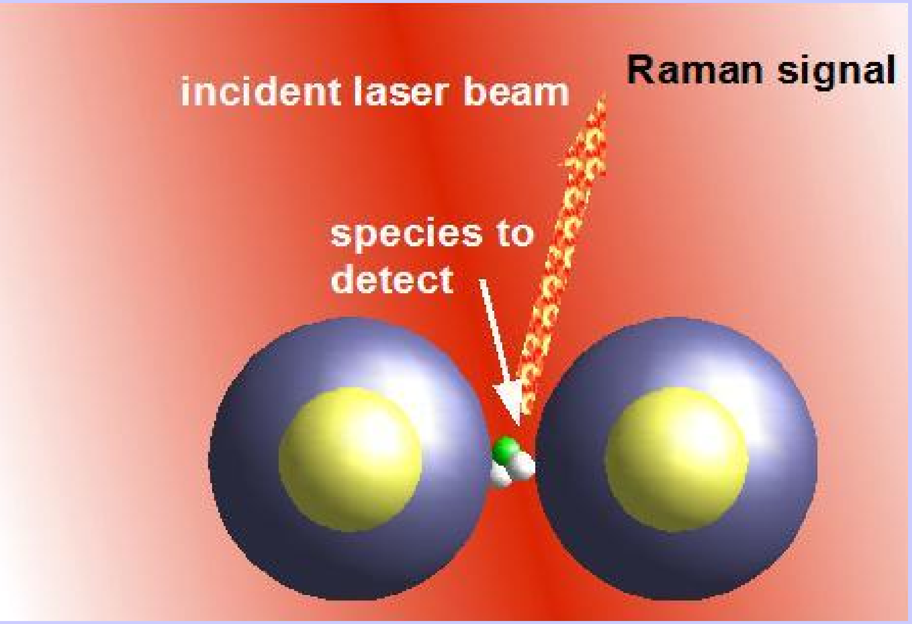
Motivation

Confinement of light in the nanoscale via
non-propagating localized surface plasmons (LSP)



Tayloring the plasmonic properties of nano systems
(resonance positions, maximum field enhancement)

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How to Understand Plasmons

Nomenclature:

Plasmon – quantized electron plasma oscillation
Polariton – coupling of a photon to a material's excitation

→ *Surface Plasmon-Polariton* (surface localized)

Evanescent waves are special transversal waves:

- exponential decay due to complex k-vector
- existence at surfaces and interfaces
- strong resonances (coupled to plasma oscillations)

top: Lycurgus cup: green for externally and red for interiorly lighting
bottom: solutions of colloid nano-crystals: silver, gold and coagulated gold

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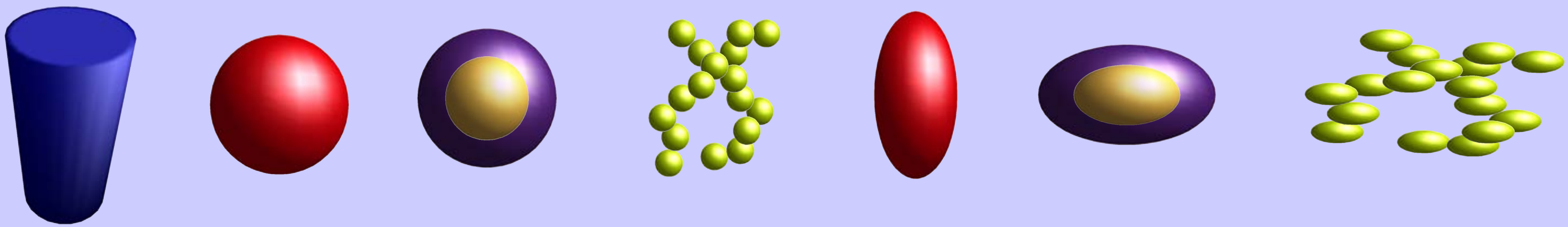
The Scattering Problem

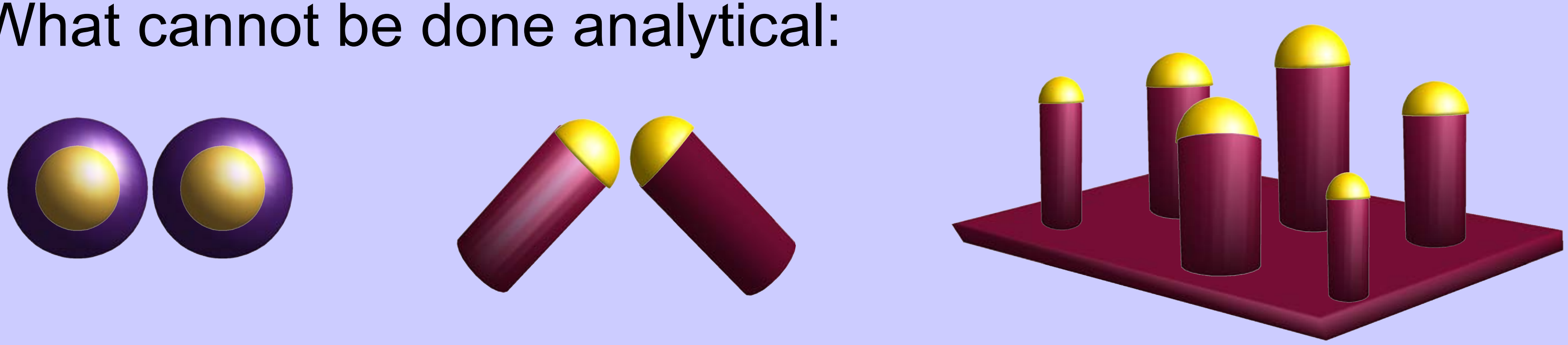
Analytical solutions available for:



Information available:

near- and far-field possible, but common Mie-type codes restricted to far-field

What cannot be done analytical:



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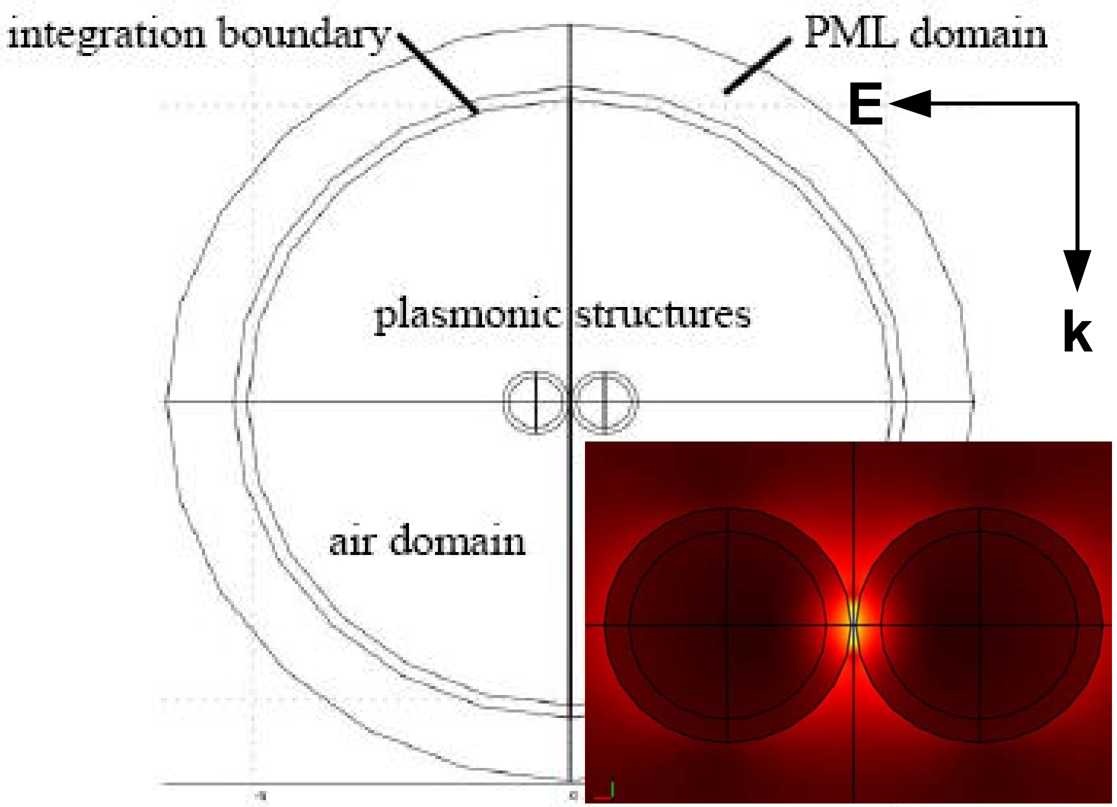
Modeling

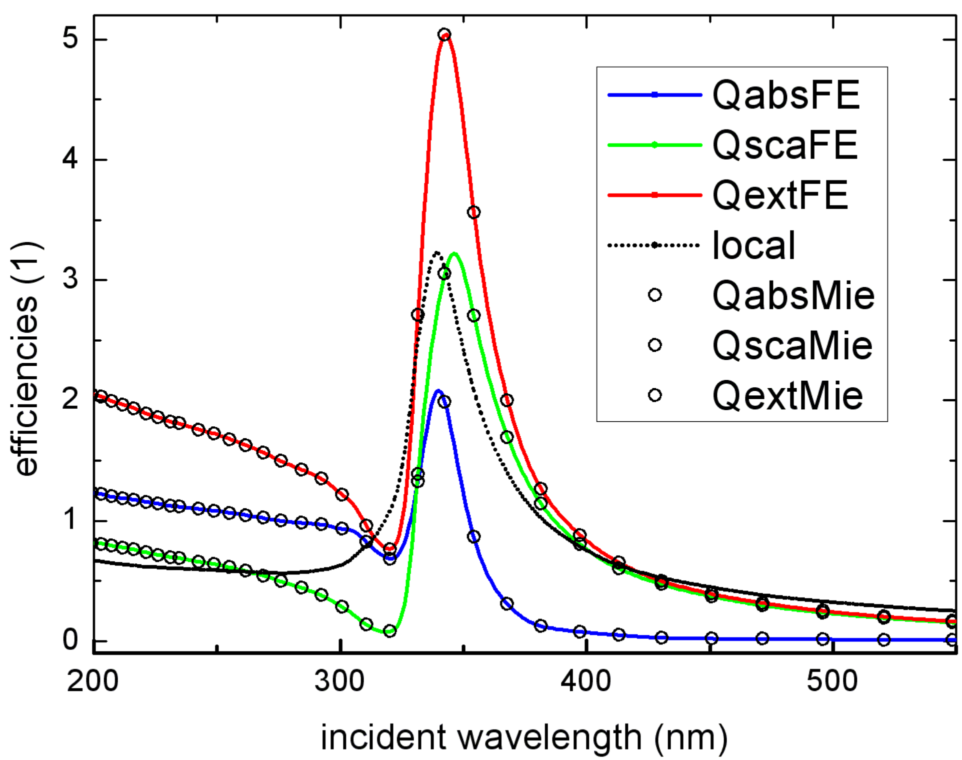


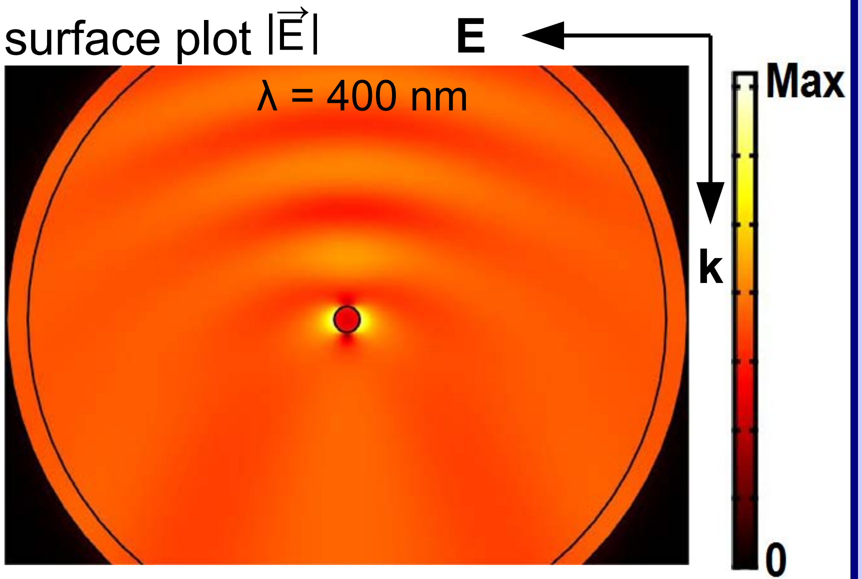
- Scattering mode of RF-module for solution of Helmholtz-equation
- Incident field normalized and polarized along the dimer axis
- Dimer spacing 2 nm
- Definition of radial components of Poynting vectors in global expressions
- Visualization of surface charges using boundary expressions separately for each of the active interfaces

Circular active domain surrounded by PML's with a bimetal nanoshell dimer inside.
The inset shows the plasmonic lightening of this three-dimensional structure.

Test – infinite silver cylinder

Comparison of Mie's solution with FEM





FE provides not only for the far-field efficiencies but also for complete near-field information.

Analytical solution with modified Fortran code compared to 2D FE:
infinite silver cylinder with 30 nm radius

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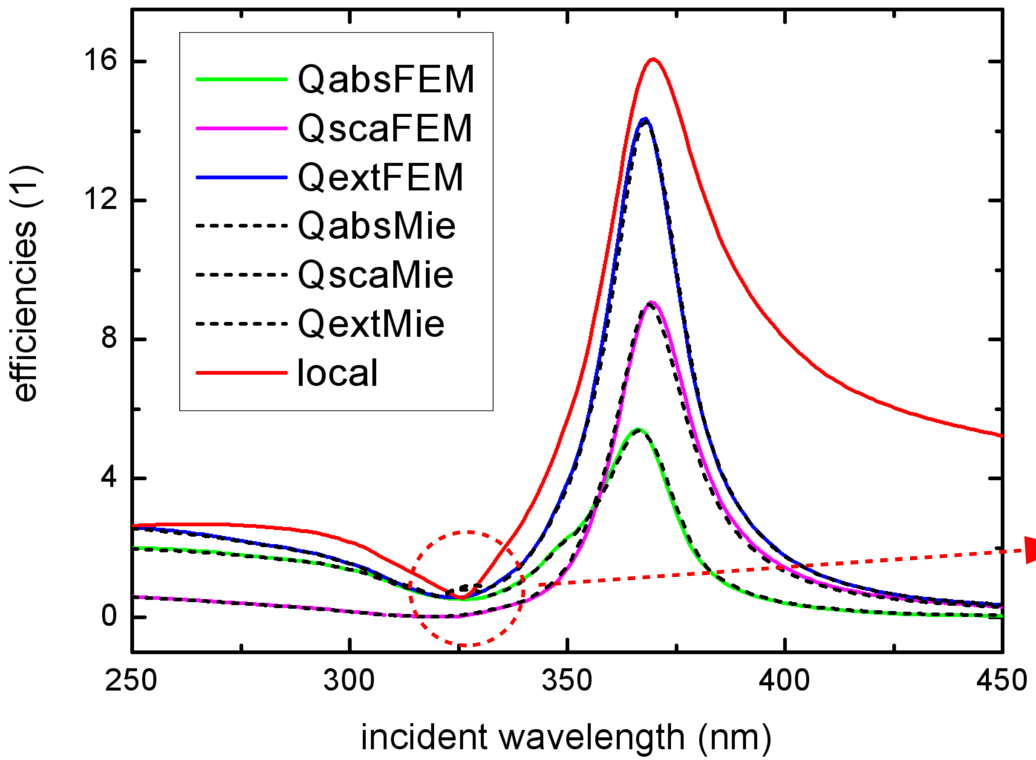
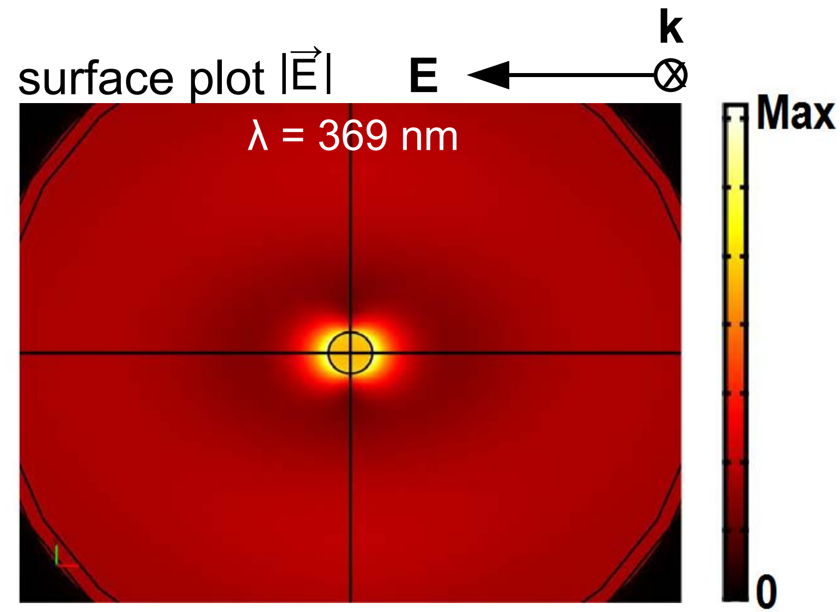
Test – pure silver sphere

Comparison of Mie's solution with FEM





Far-field:
good agreement except of a small Mie-feature at 330 nm.

Analytical solution with modified Fortran code compared to 3D FE:
silver sphere with 30 nm radius

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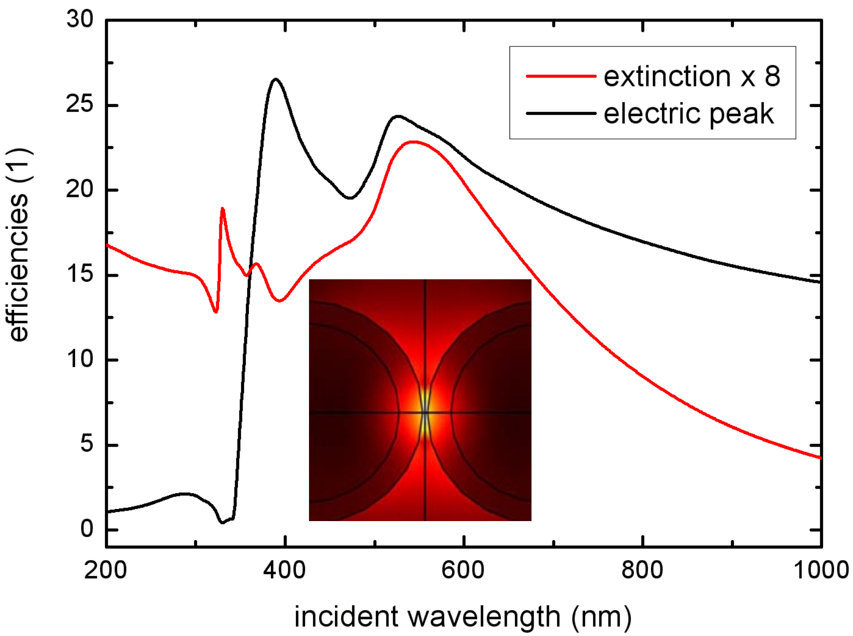
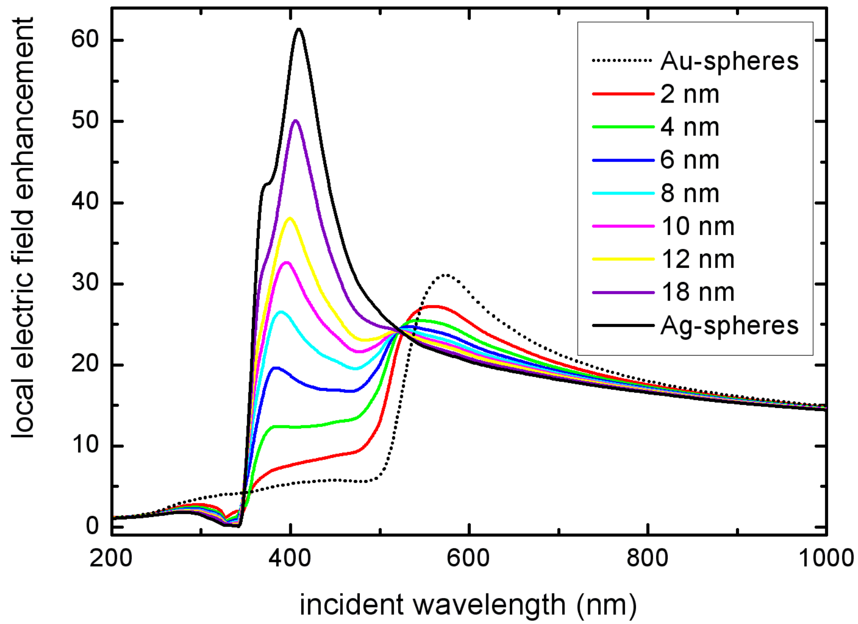
Bimetallic nanocylinder dimer

Far- and near-field information



Extinction efficiency does not match the local field enhancement factor E_{peak}/E_{inc} for an Ag@Au (42,50)-nanocylinder dimer with 2 nm spacing.

Influence of shell thickness



Local electric field enhancement factors E_{peak}/E_{inc} in the hot-spots of Ag@Au dimers with varying shell thicknesses. Pure metal cylinder dimers for comparison.

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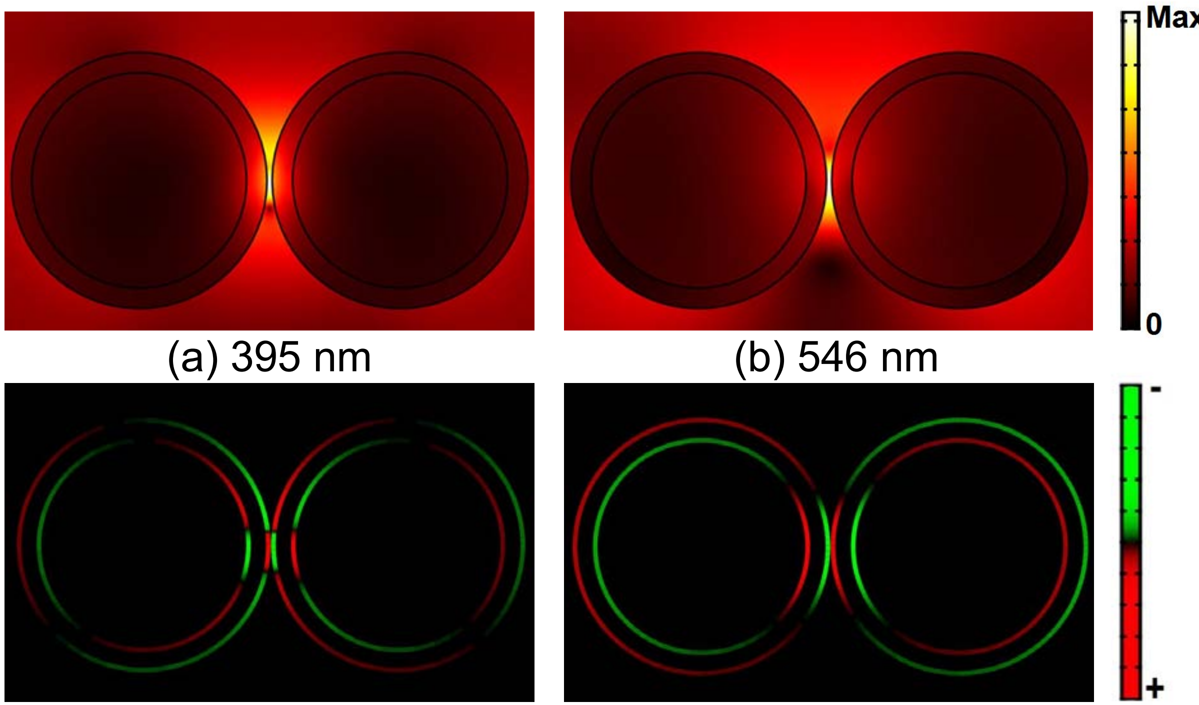
Visualization of surface charges



- Polar character of plasmon resonances visible:

  395 nm – quadrupolar,
  546 nm – dipolar

- Resonances concentrated to the hot-spot
- No explicite coupling behaviour for bimetallic structures

Visualization of the plasmon resonances in an Ag@Au (42,50)-cylinder shell. Surface plots of (a) and (b) show the electric field enhancement factor E_{peak}/E_{inc} while the corresponding polarization charges are shown thereunder.

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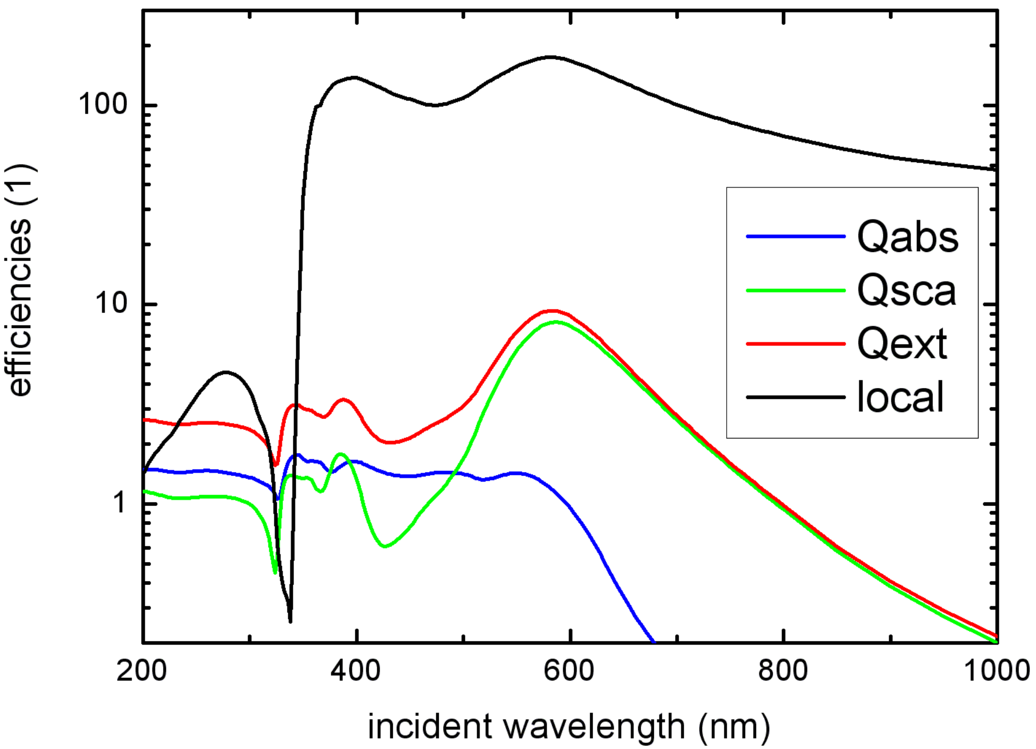
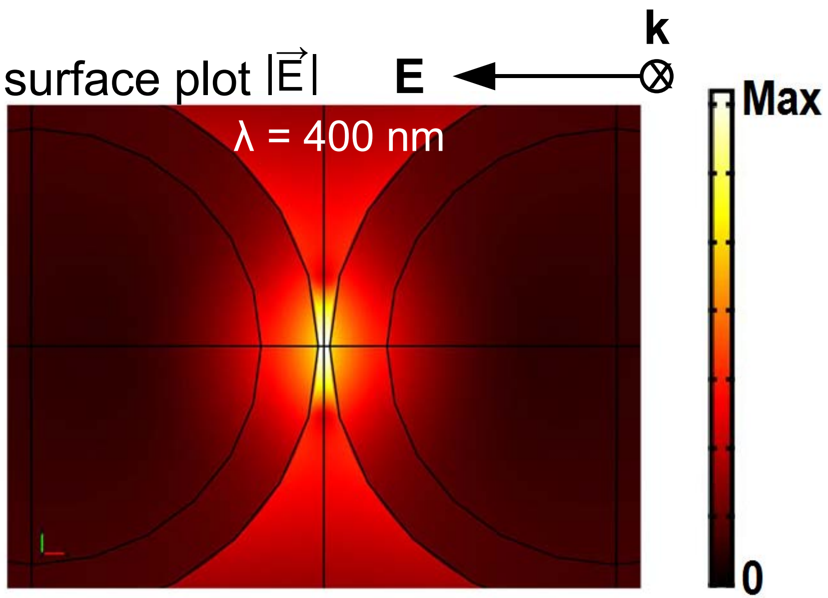
Bimetallic nanoshell dimer

Far- and near-field information





Local enhancement factors >100 in a wide range of wavelengths from 370 nm to 700 nm.

Efficiencies of absorption, scattering and extinction compared to the local enhancement factor of an Ag@Au (40,50) bimetal shell dimer with 2 nm spacing.

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Conclusion

Modeling:

2D → good convergence, not realistic
3D → realistic modeling, long solving duration

Physics:

Dimers → 7-8 times greater local enhancement in hot-spots
Bimetallic shells → tunability, no specific coupling

Therefore 3D bimetallic nanoshell dimers ensure great local enhancements in a wide range of wavelength!
→ ideal for spectroscopy using the Raman effect

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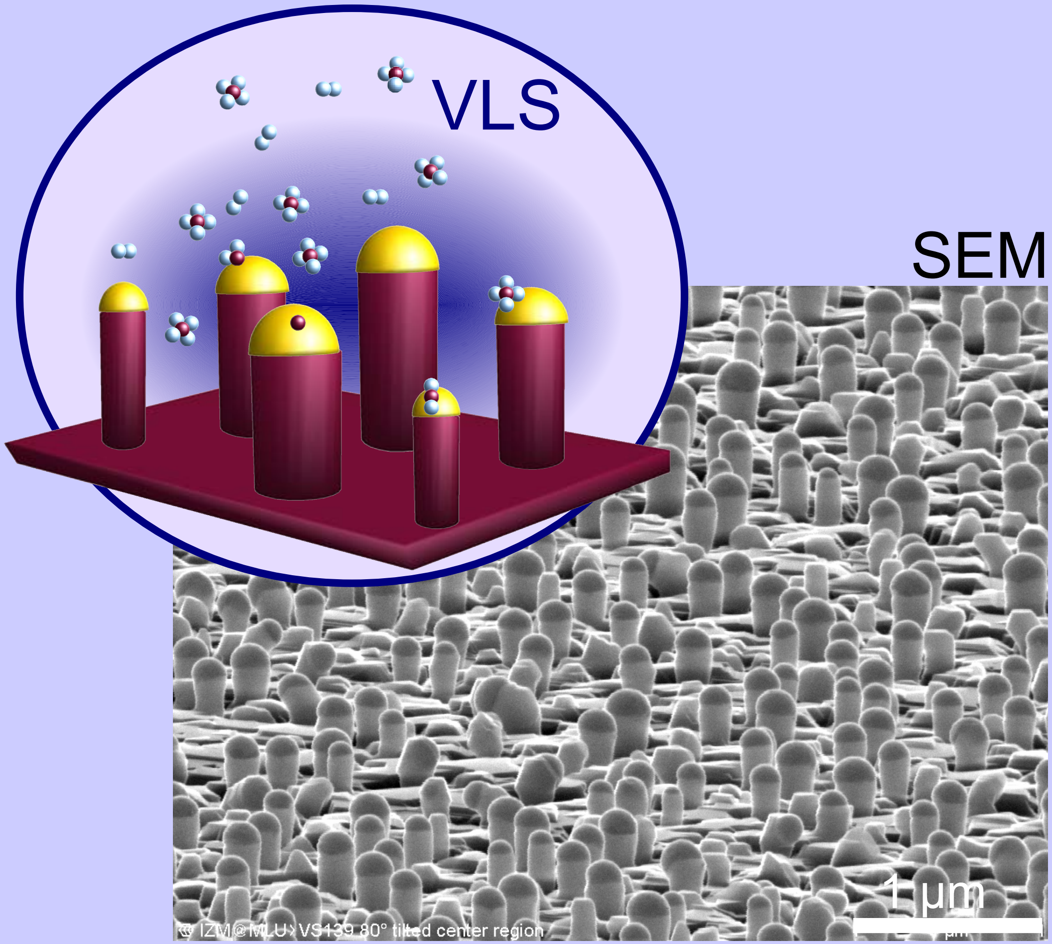
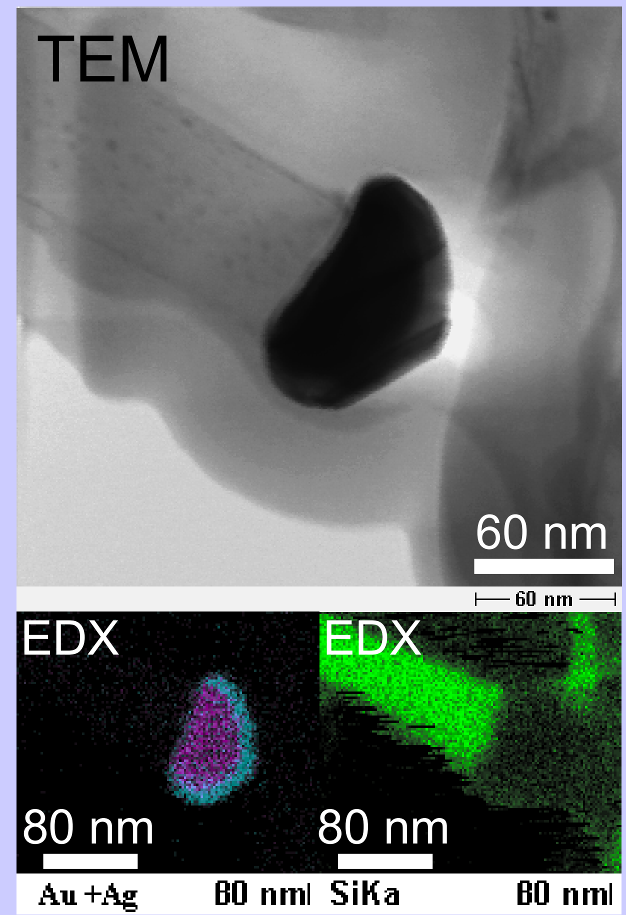
Outlook

Design of custom made plasmonic nanostructures for applications
e.g. surface enhanced Raman → single molecule spectroscopy





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