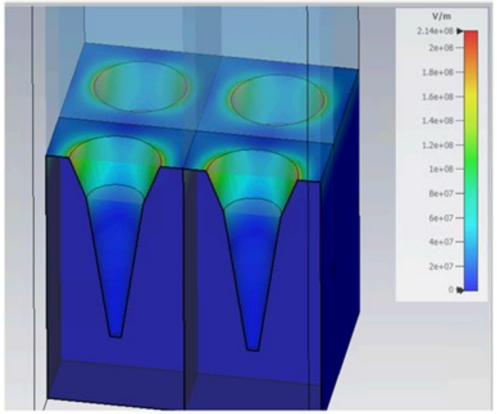
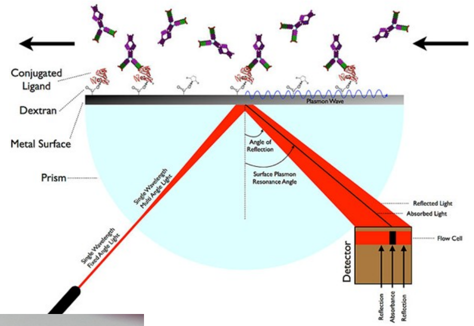
Plasmonic Photocathode Program at DESY

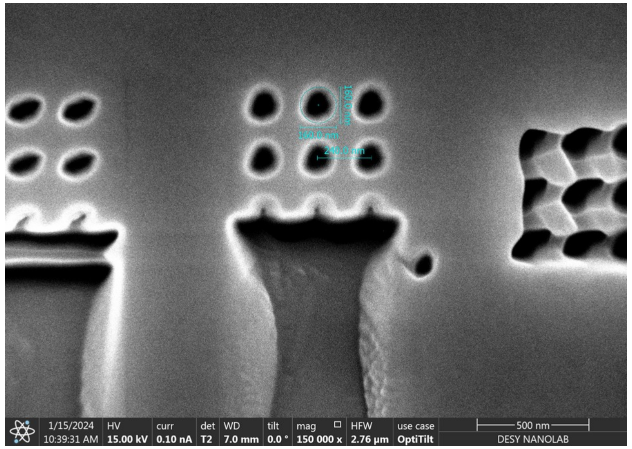


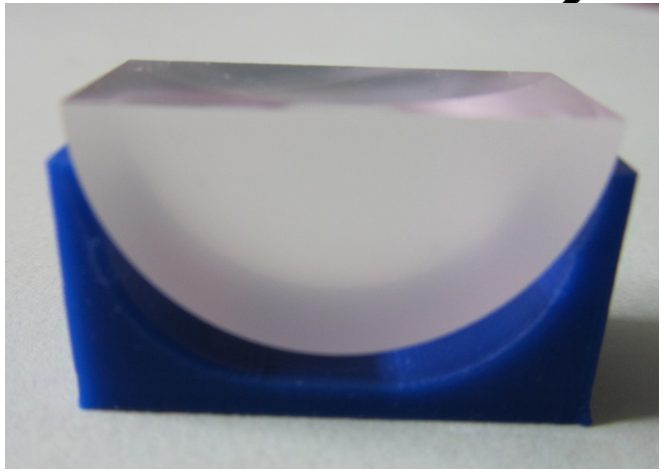
UBA Workshop 2024

K. Floettmann, Ch. Banjare, D. Bazyl

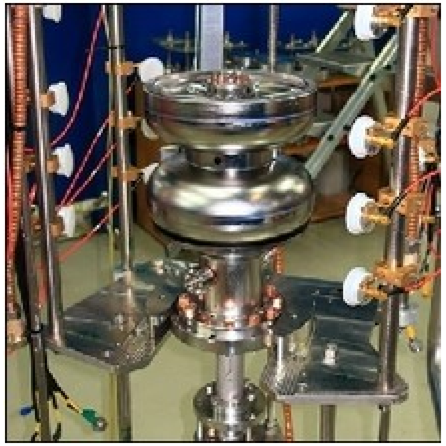
18th of June 24

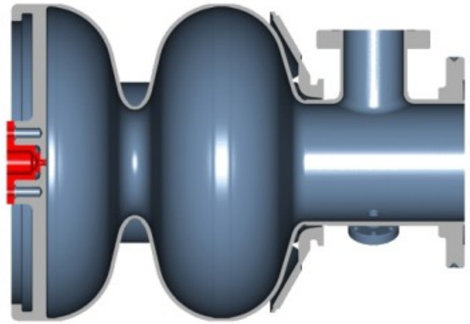


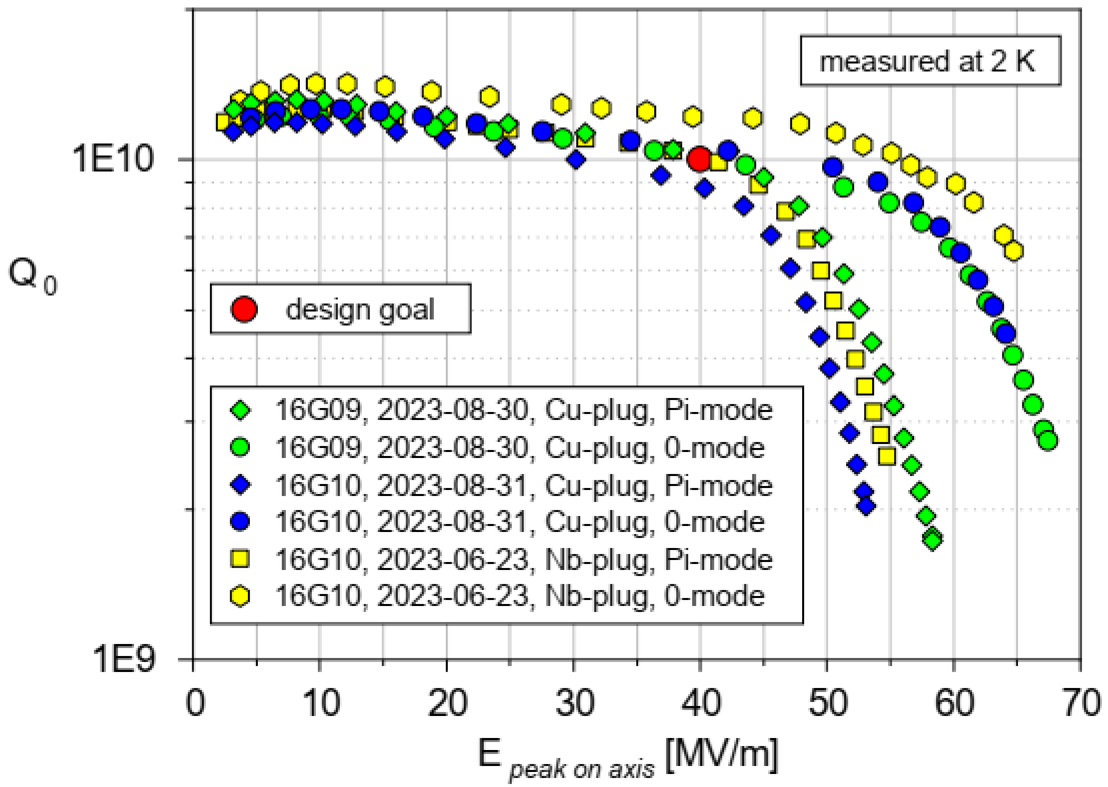




High QE Plasmonic Cathode for Superconducting Gun



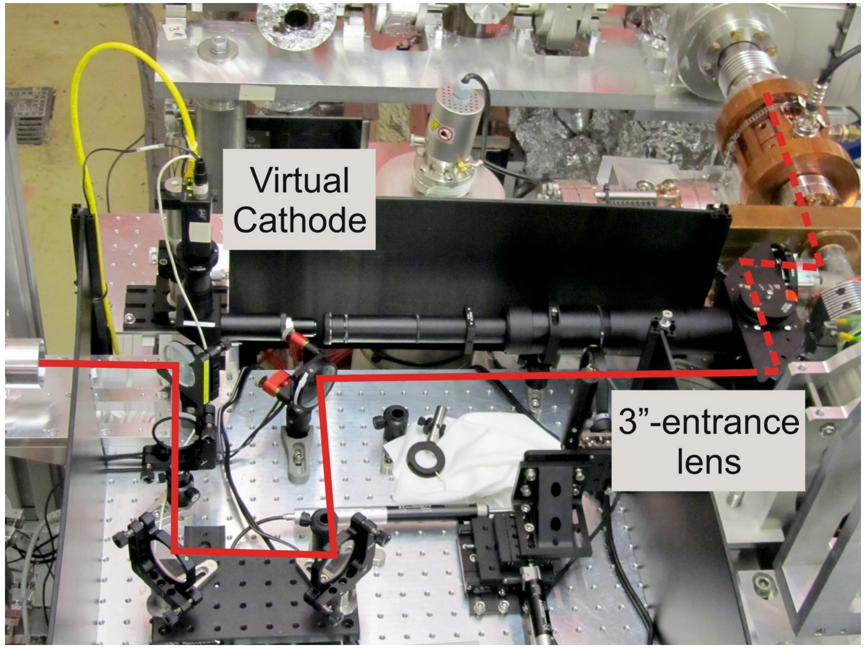


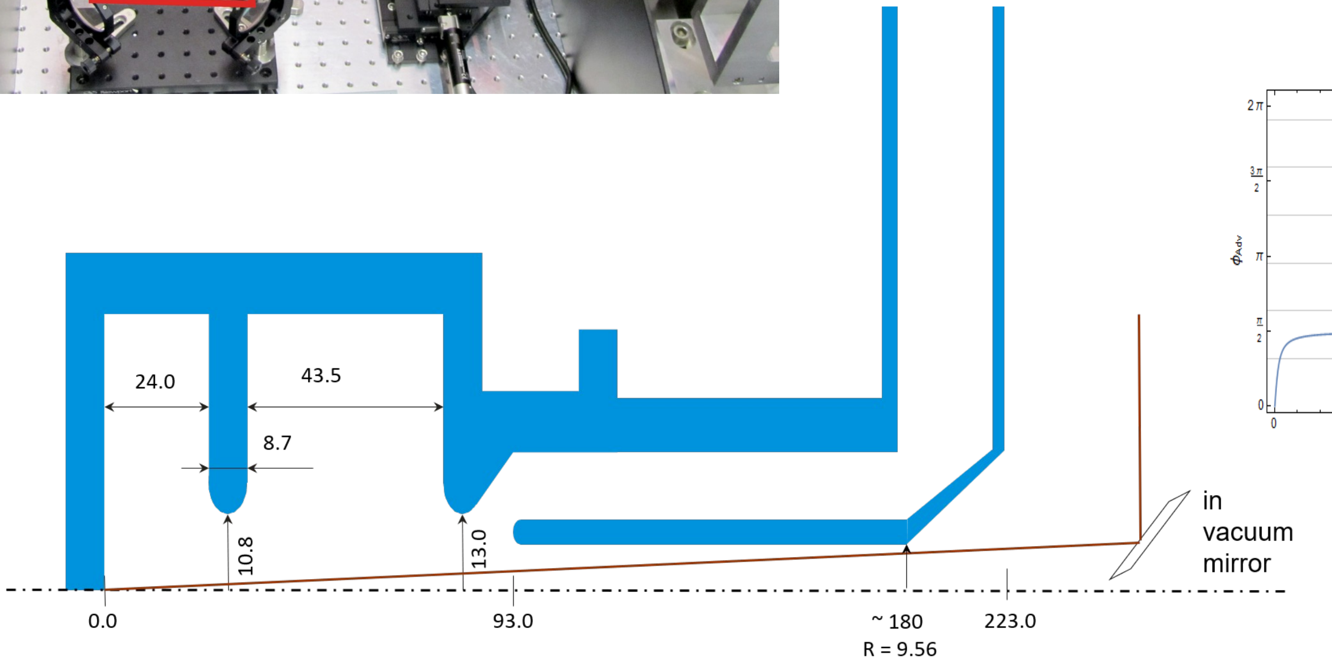


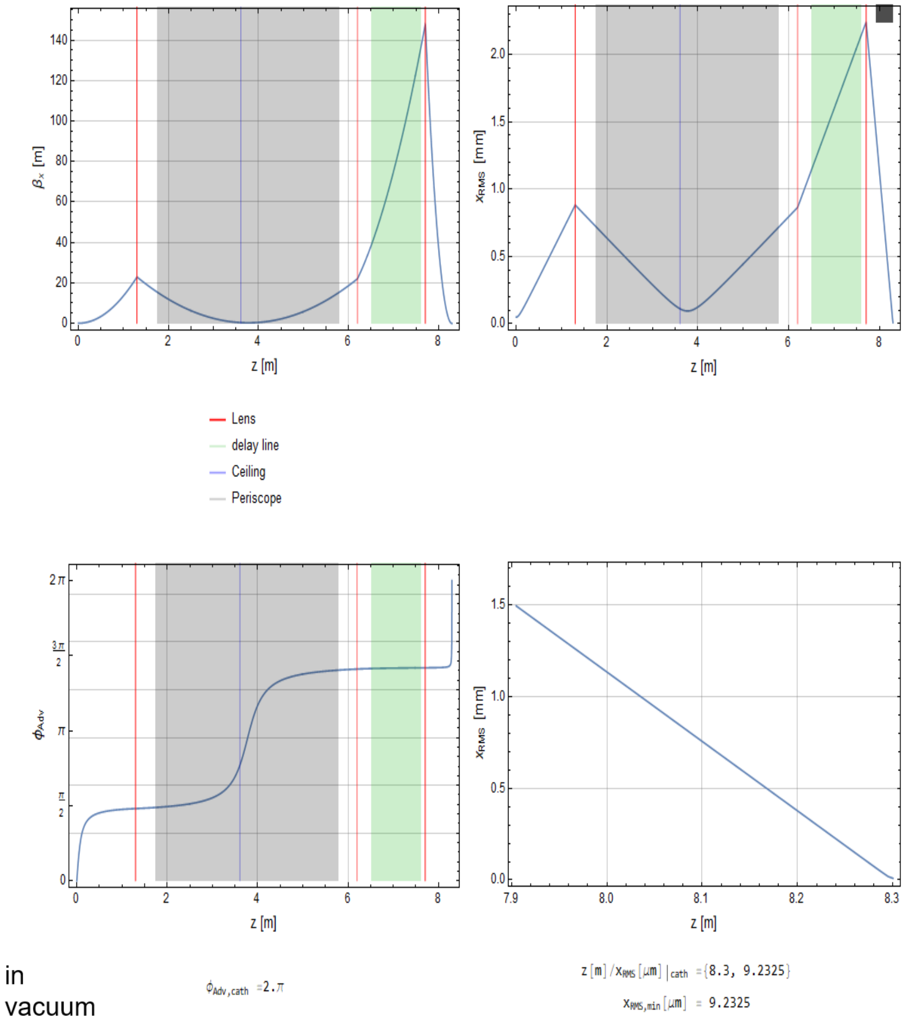
E. Vogel et al. 'High gradients at SRF photoinjector cavities with low RRR copper cathode plug screwed to the cavity back wall', arXiv:2310.02974v1 (2023).

On-axis fields of up to 55 MV/m
(65 MV/m in the 0-Mode)

Small Area Plasmonic Cathode for REGAE





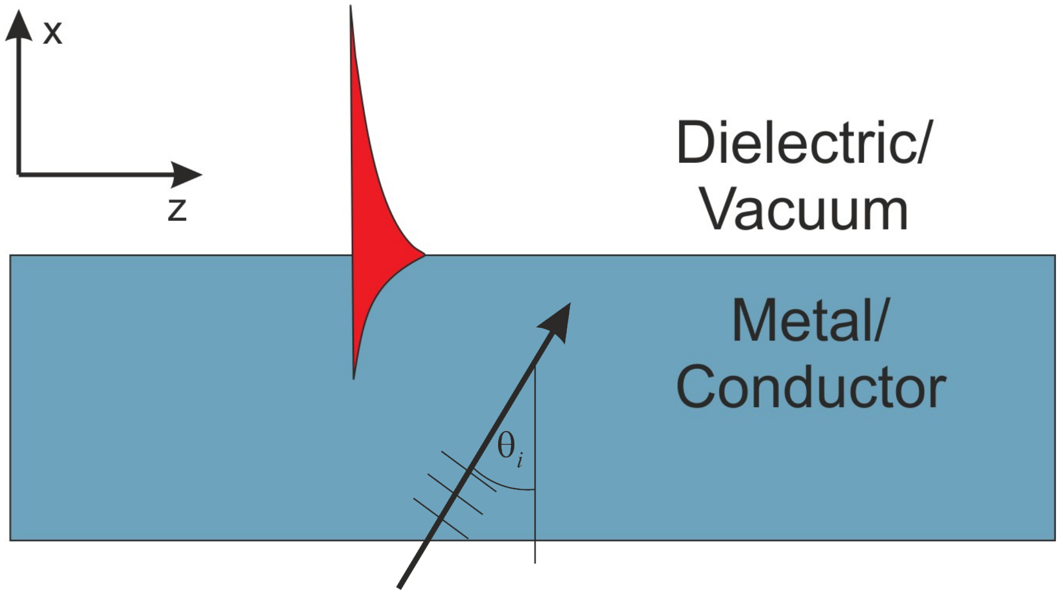


Outline

- Physics of Surface Plasma Waves
- Back Illumination cathode
- Structured Photocathodes for Front Illumination
- Plasmonic Lens Structures

Surface Plasma Wave (SPW)

a surface wave travelling along a metal – dielectric interface (Sommerfeld-Zenneck wave), exponentially decaying amplitude perpendicular to the surface



propagation length: 10 – 60 µm

$$e^{i(k_x x + k_z z - \omega t)}$$

$$\tan\theta_i = \frac{k_z}{k_x}$$

$$k_x = \sqrt{\varepsilon k_0 - k_z}; \quad k_0 = \frac{\omega}{c}$$

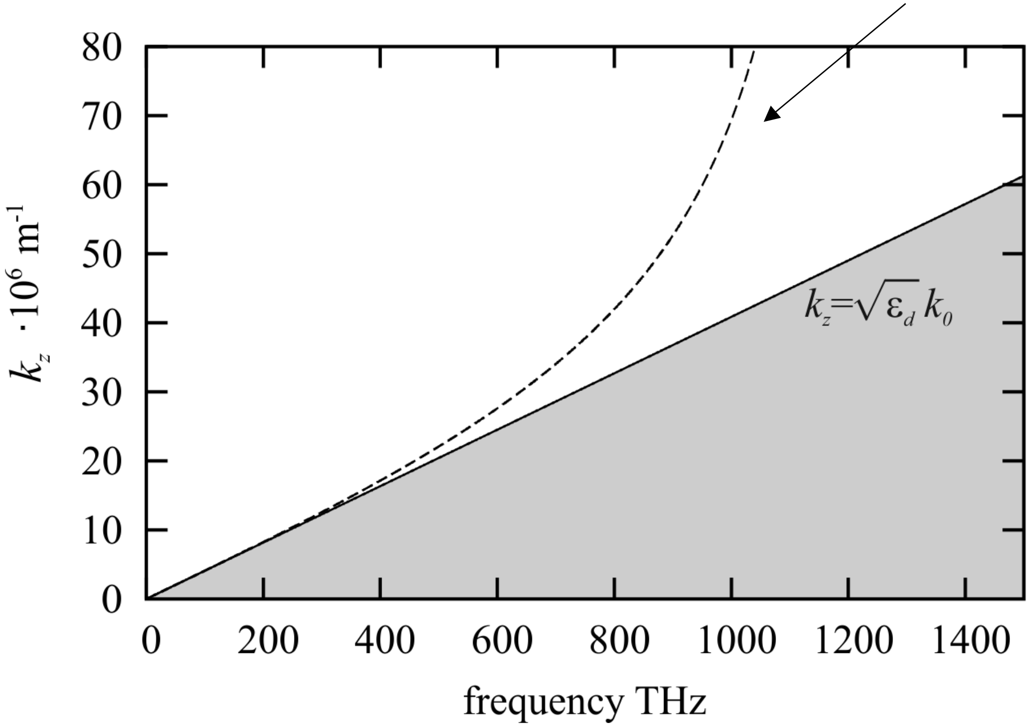
k_x needs to become imaginary to get an exponential decay of the amplitude

- metal: Re(ε) is negative
- (lossless) dielectric: evanescent field

J. Zenneck 'Über die Fortpflanzung ebener elektromagnetischer Wellen längs einer ebenen Leiterfläche und ihre Beziehung zur drahtlosen Telegraphie', Annalen der Physik (1907).
A. Sommerfeld 'Über die Ausbreitung der Wellen in der drahtlosen Telegraphie', Annalen der Physik (1909).

Surface Plasma Wave

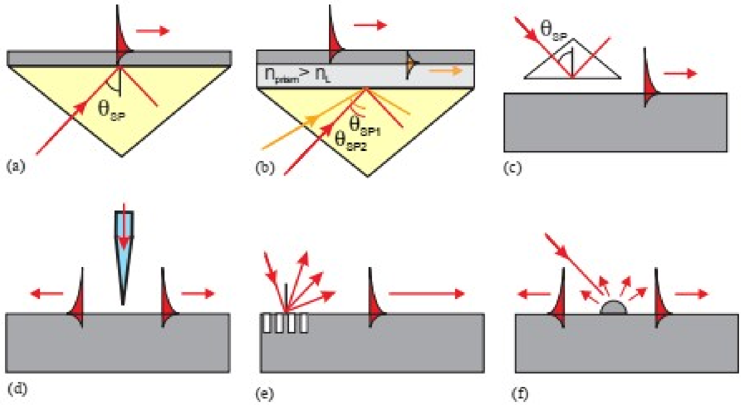
$$k_z^{SPW} = k_0 \sqrt{\frac{\varepsilon_d \varepsilon_m}{\varepsilon_d + \varepsilon_m}}$$



$$\theta_{i,\max} = 90°$$

$$k_{z,\max} = \sqrt{\varepsilon}\, k_0$$

light reflecting from a metal surface cannot couple to an SPP!

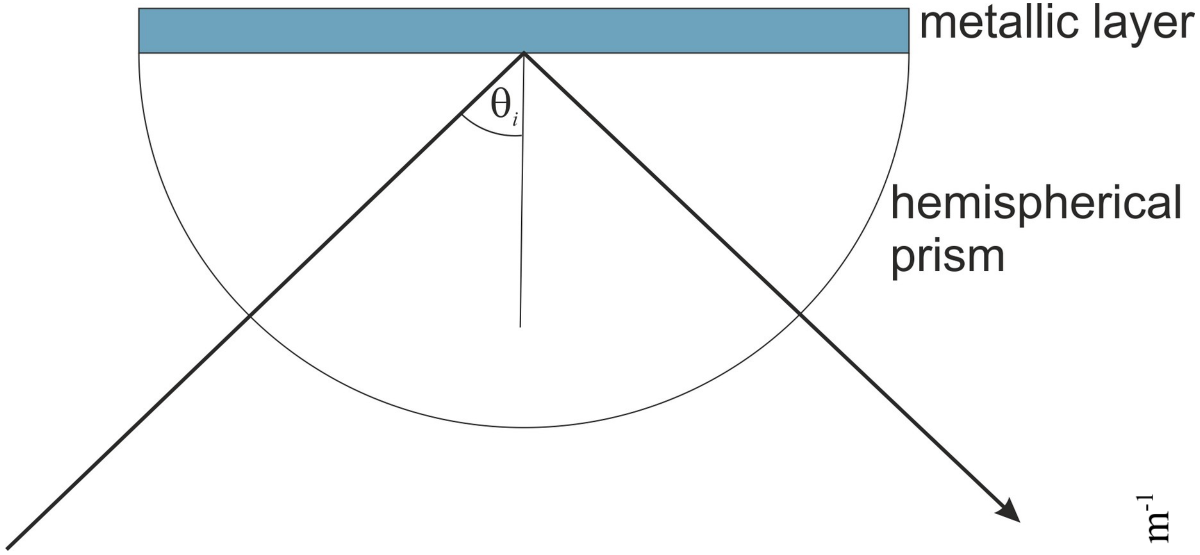


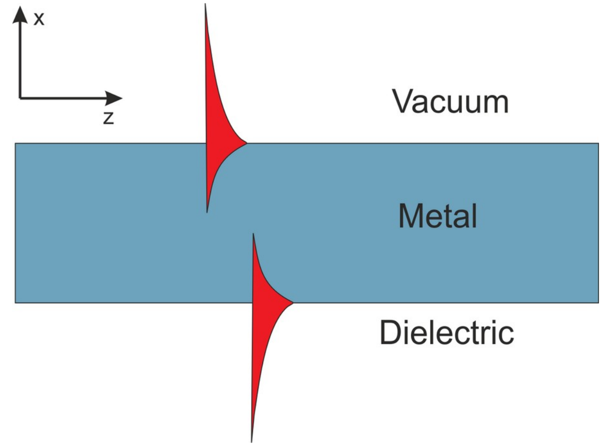
SPW excitation configurations; ATR setup (a-c), SNOM=scanning nearfield optical microscope (d), diffraction grating (e), surface defects (f).

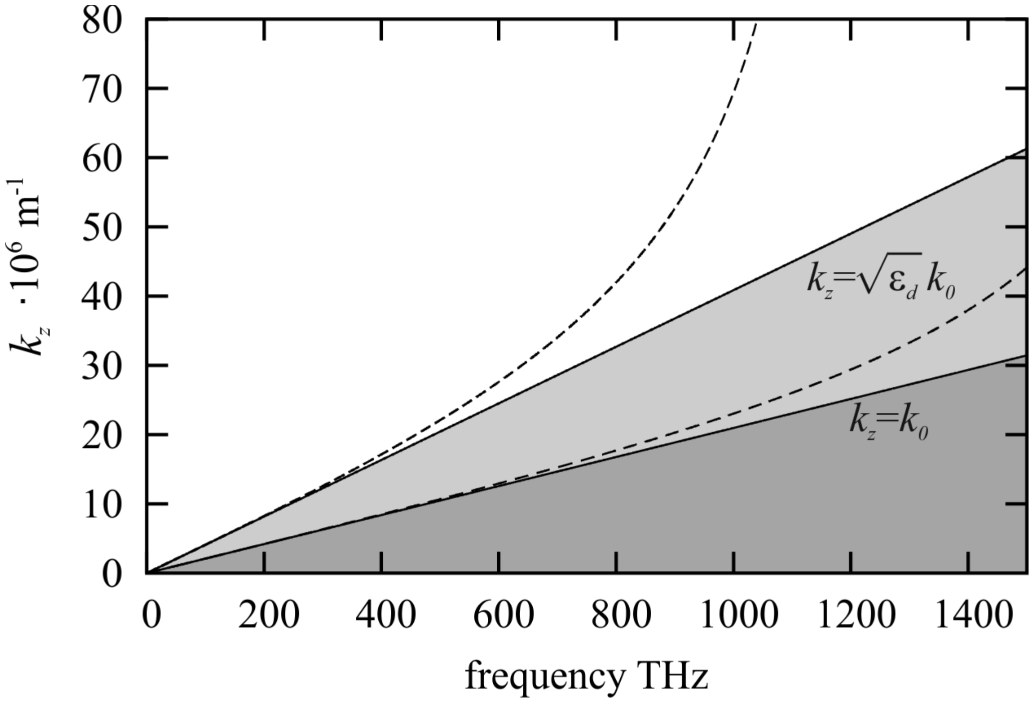
electron beams: (cathode luminescence)

A. V. Zayats et al. ‘Nano-optics of surface plasmon polaritons’, Physics Reports 408 (2005).

Attenuated Total Reflection Setup

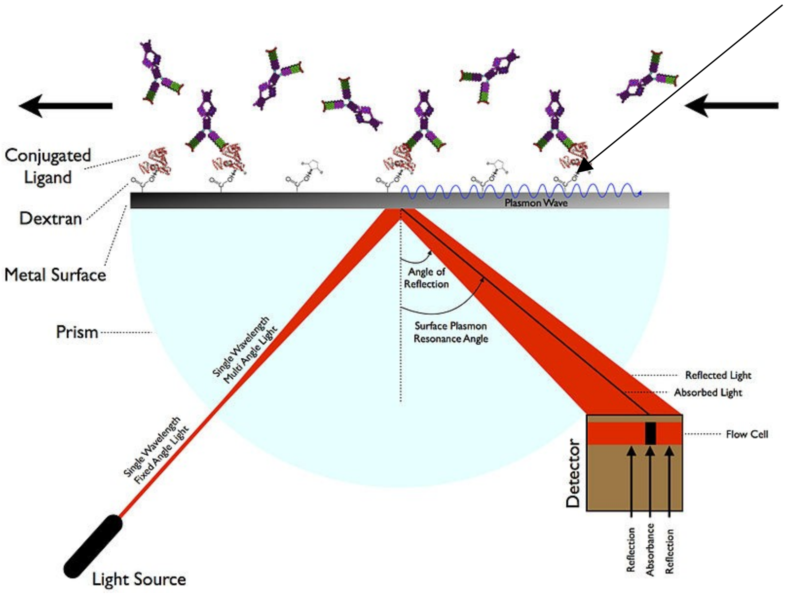






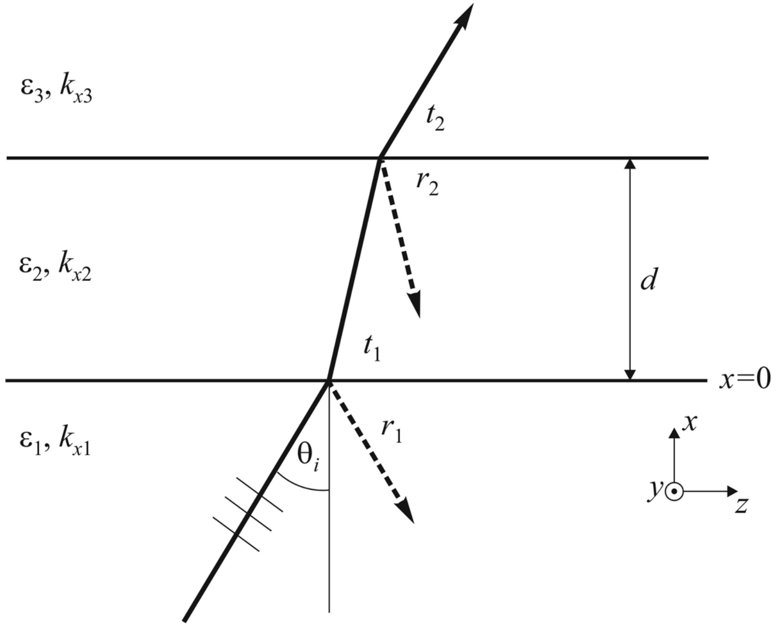
Attenuated Total Reflection Setup

Is it really propagating?



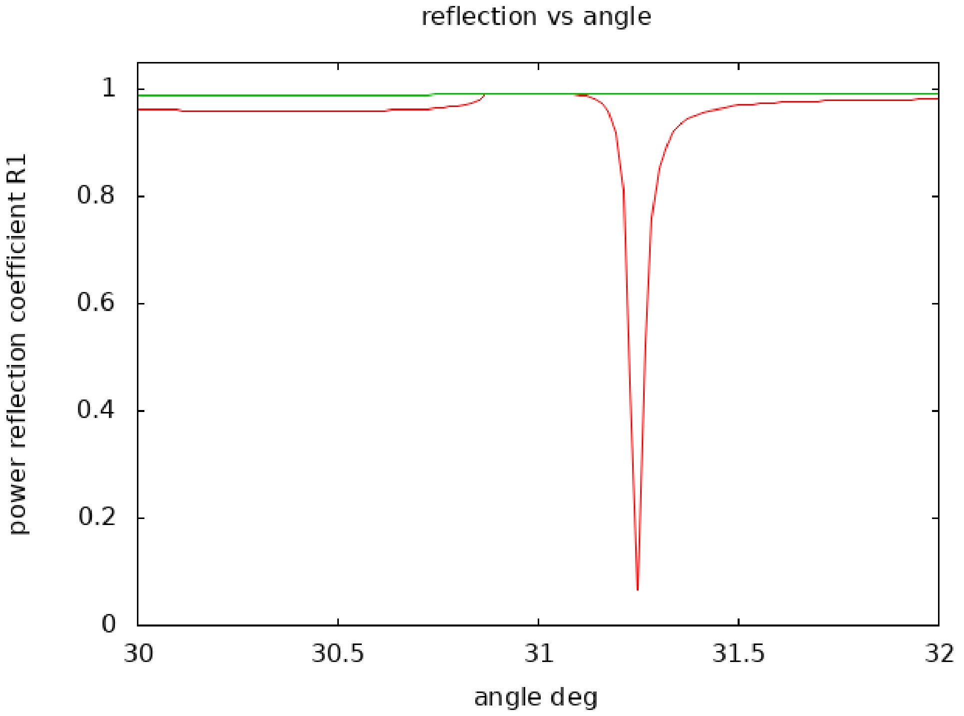
https://en.wikipedia.org/wiki/Surface_plasmon_resonance

Fresnel Equations

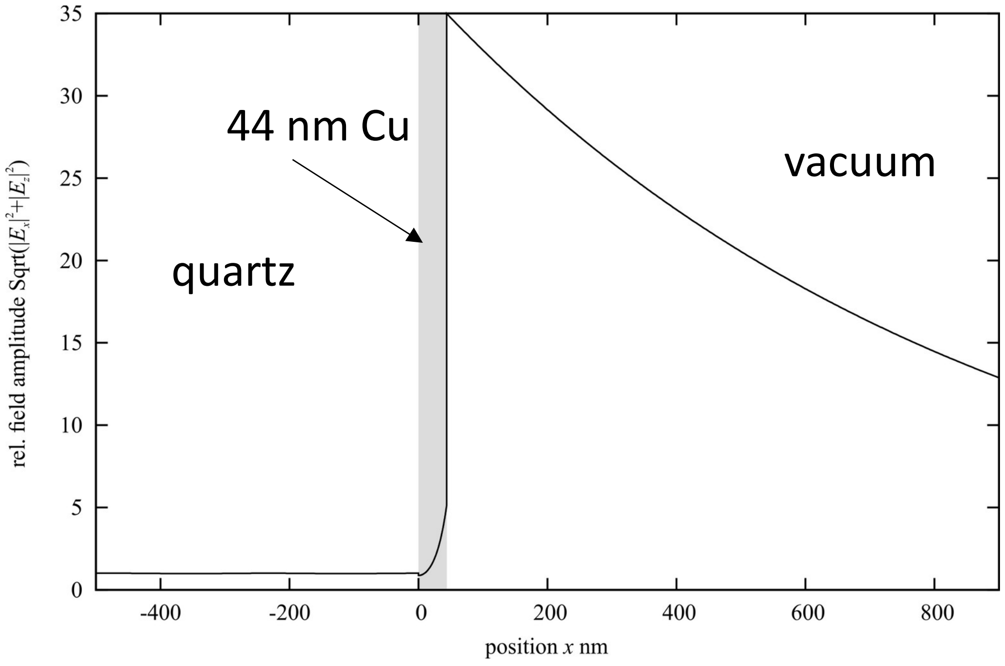


Attenuated Total Reflection Setup

Hemispherical quartz prism with 40 nm Copper layer (Drude model), 800nm incident light



Power reflection coefficient vs. incident angle
p-polarized light (red), s-polarized light (green)



Development of the field amplitude through the ATR-setup; normalized to the field in the prism.

Photoelectric Emission Experiments

PHYSICAL REVIEW B VOLUME 43, NUMBER 11 15 APRIL 1991-I

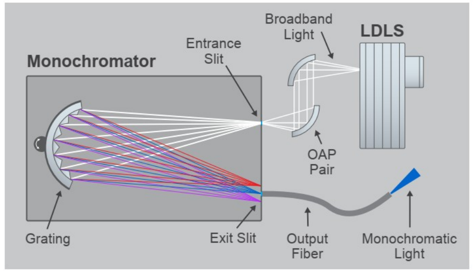
Surface-plasmon field-enhanced multiphoton photoelectric emission from metal films

T. Tsang, T. Srinivasan-Rao, and J. Fischer
Brookhaven National Laboratory, Upton, New York 11973
(Received 29 June 1990)

(In) Contrast to the electron emission obtained by irradiating the laser on a metal surface, electron yield increases by several orders of magnitude … … (are) observed when photons are coupled to the surface-plasmon modes of these films.

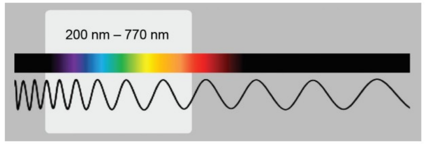
but some inconsistencies in the measurement results are reported…

Principle of Operation



We are preparing new measurements at DESY:
a coated hemispherical prism, a measurement chamber and a variable light source are available, measurements should start soon.

Wavelength Range



Side Note:
Can we excite an SPP at the metal – dielectric interface of a cylindrical waveguide?

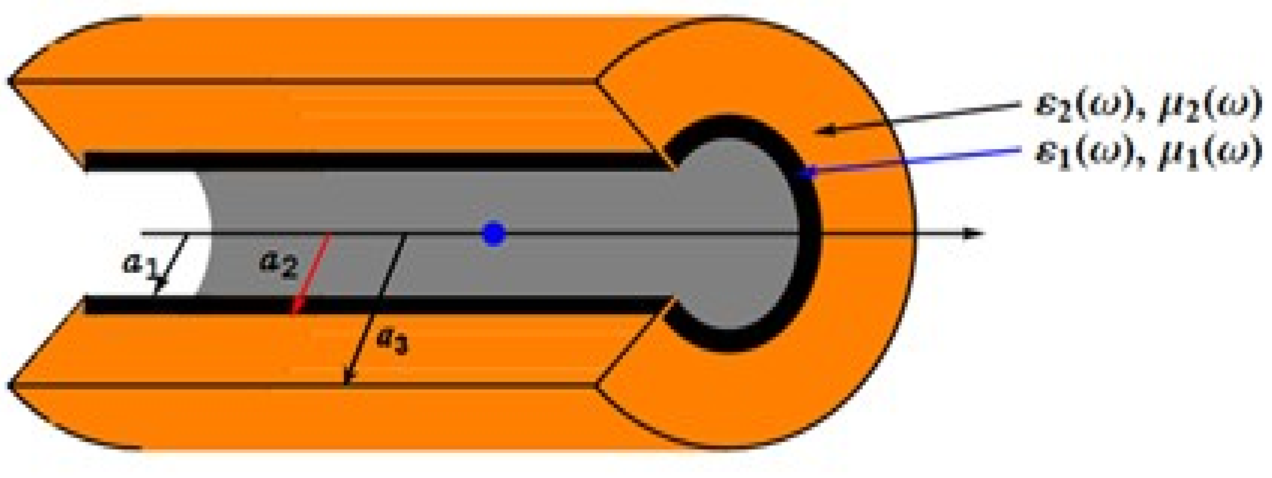
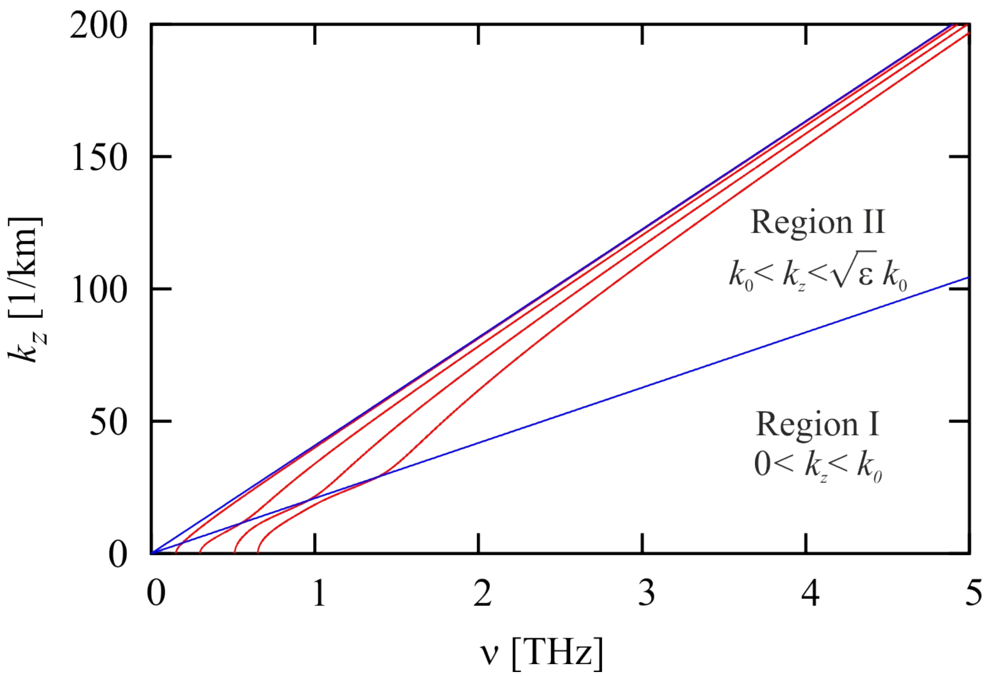
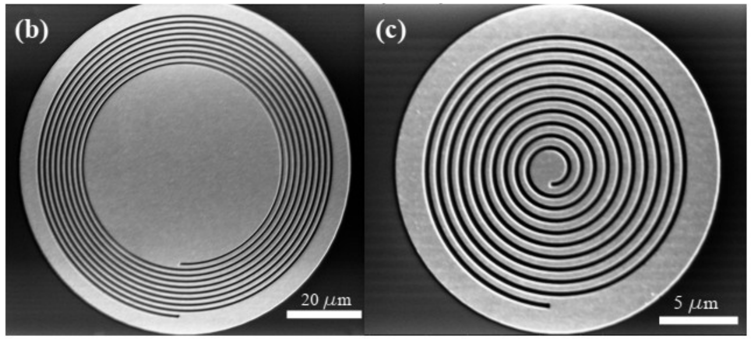


Figure 1. Two-layer metal-dielectric cylindrical waveguide.



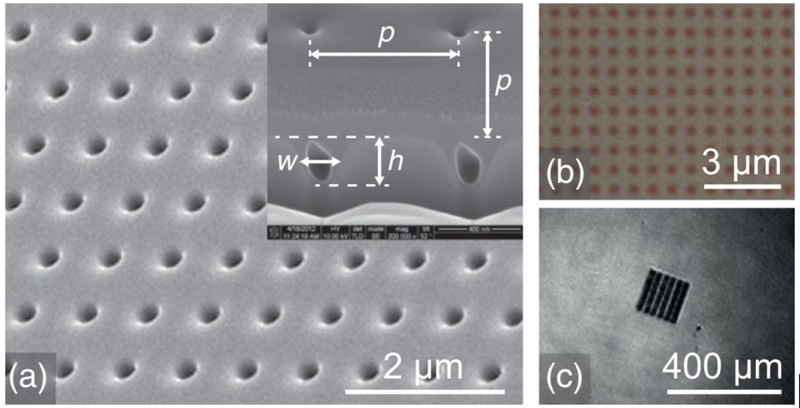
Structured surface cathodes

plasmonic lens structures.



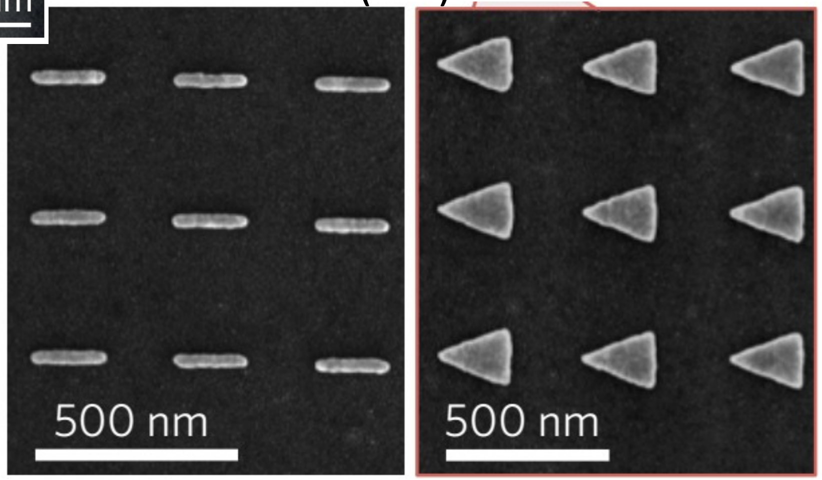
A. Kachwala et al. 'Study of nano-structured electron sources using photoemission electron microscope' IPAC 23, (2023).

Periodic array of holes, grooves…



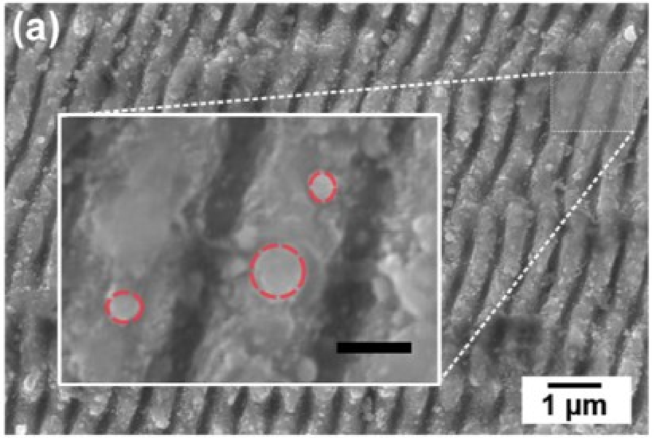
R. K. Li et al. 'Surface-Plasmon Resonance-Enhanced Multiphoton Emission of High-Brightness Electron Beams from a Nanostructured Copper Cathode', Phys. Rev. Lett. 110, 074801 (2013).

periodic array of metal antennas on conductor (ITO)



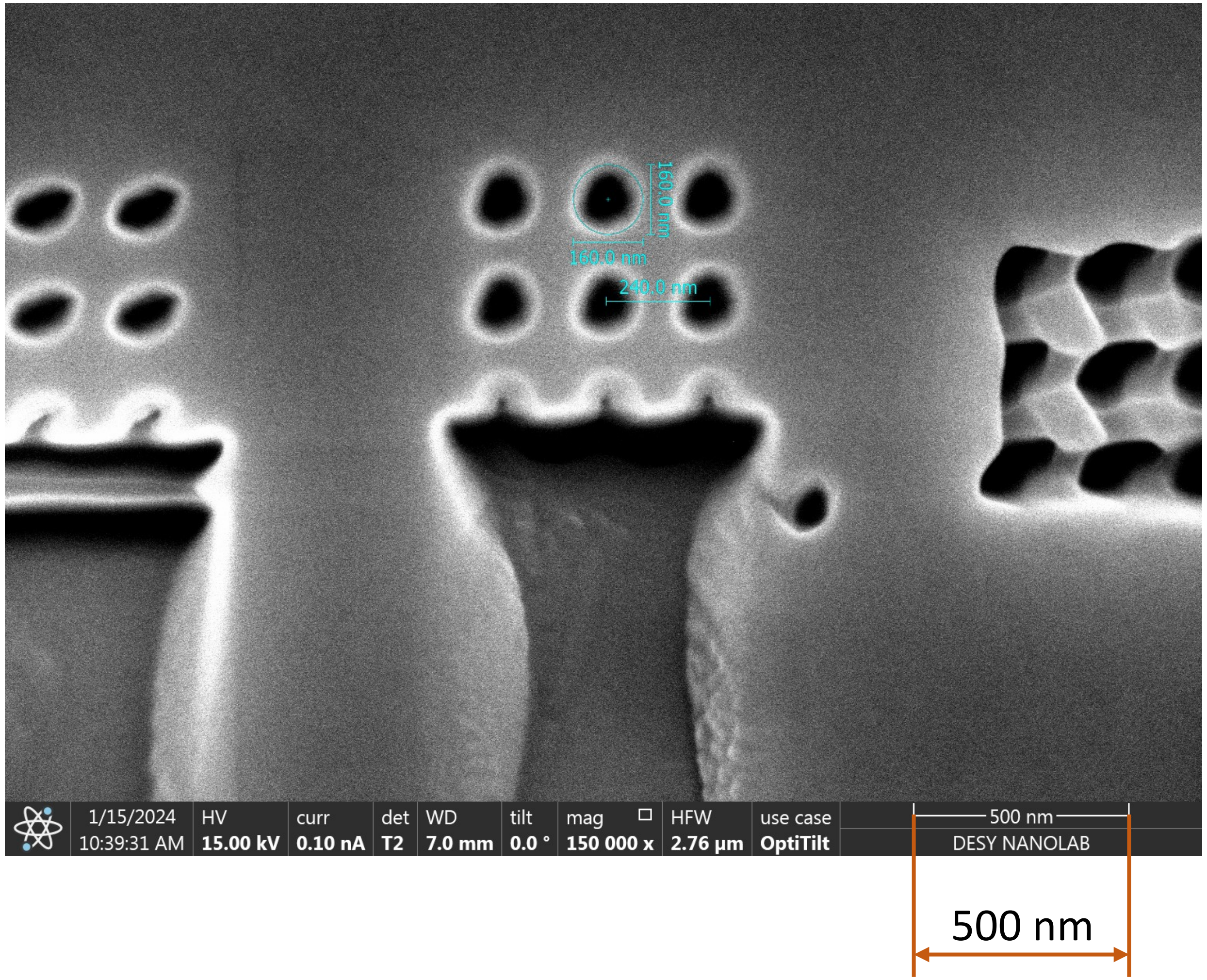
W. P. Putnam et al. 'Optical-field-controlled photoemission from plasmonic nanoparticles', Nature Phys. 13 (2017).

in-situ laser structured



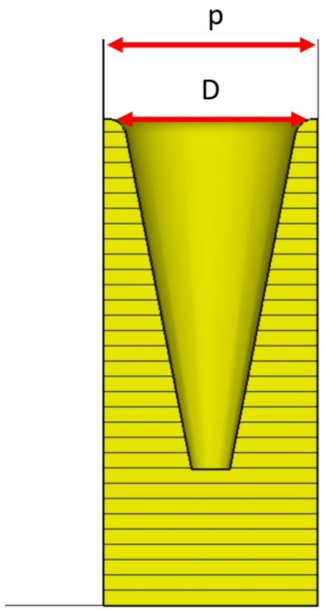
M. Martinez-Calderon et al. 'Hot electron enhanced photoemission from laser fabricated plasmonic photocathodes', Nanophotonics (2023).

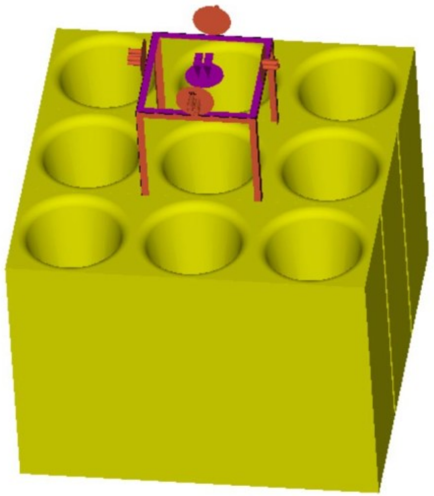
First tests at DESY in collaboration with NanoLab

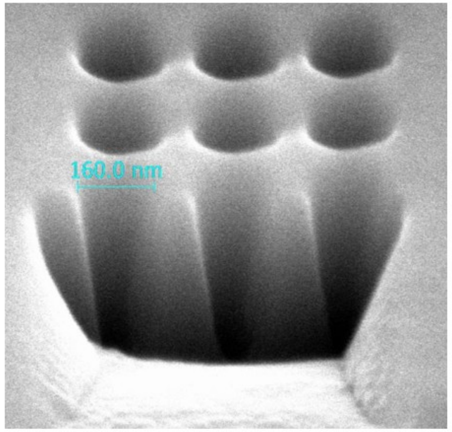


3x3 test pattern of holes in Cu produced with an Focused Ion Beam (FIB)

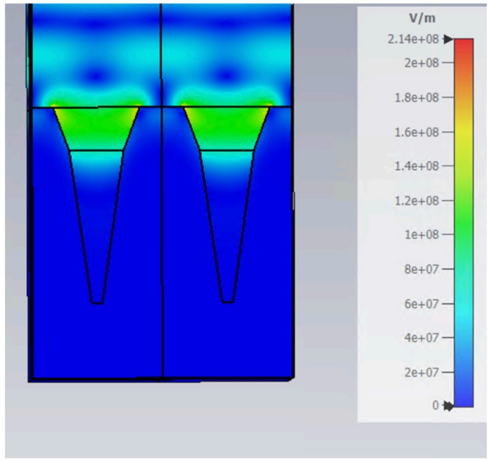
Optimization of cone shaped hole and FIB parameters

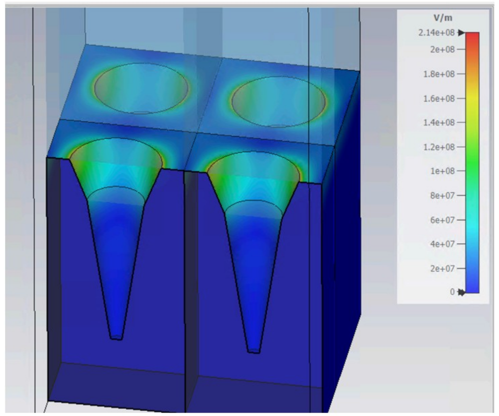




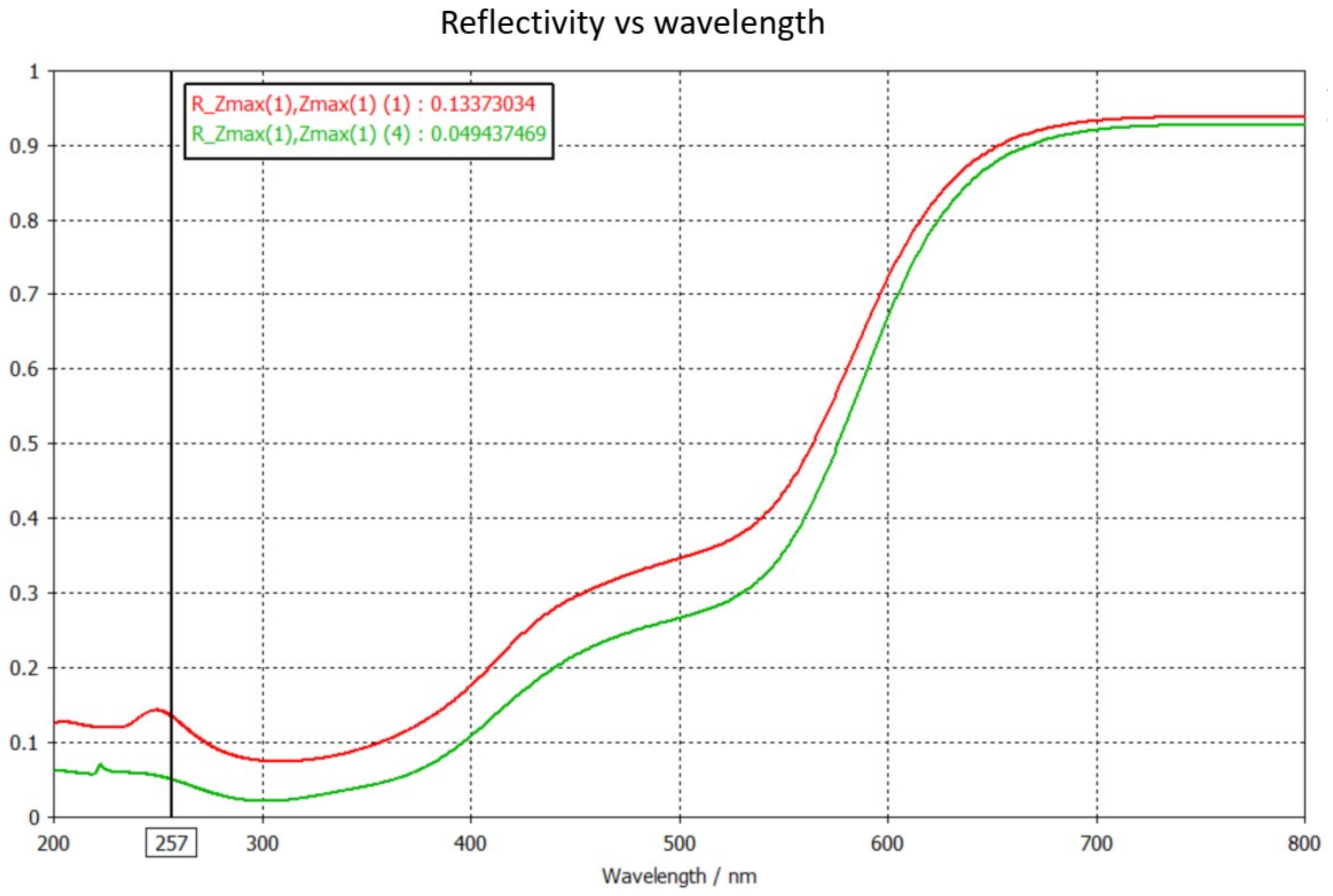


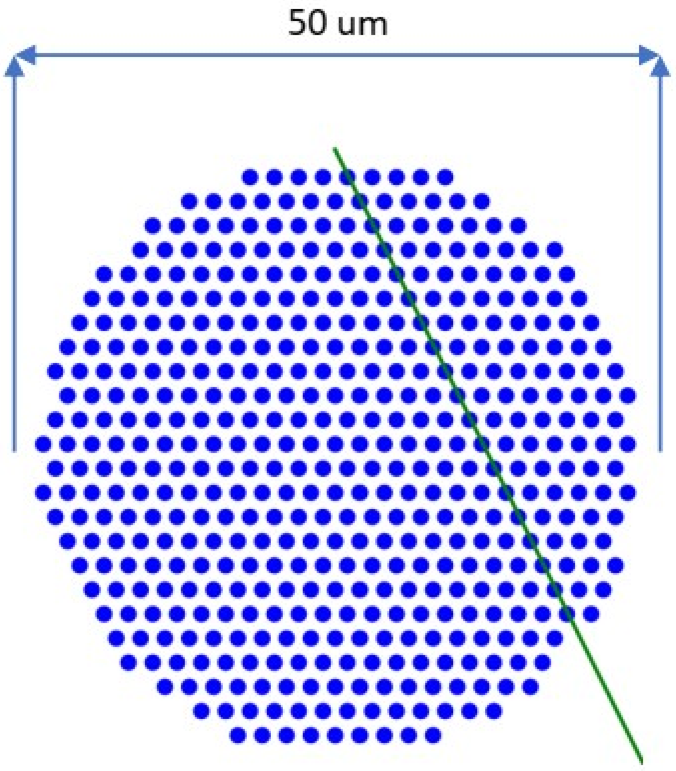
Successful test with Dry-Ice Cleaning: The Structure survives the cleaning procedure …





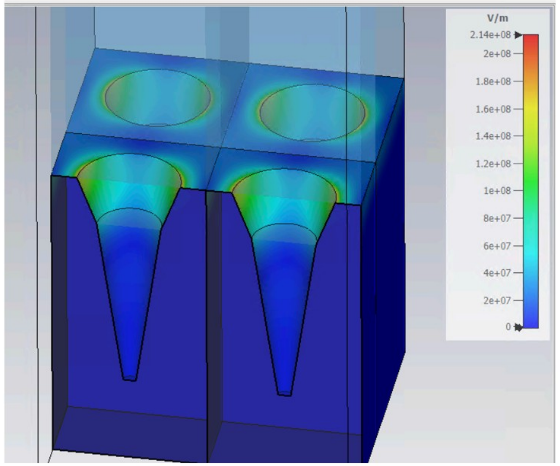
Optimized reflectivity curve and shape of cathode patch for beam test at REGAE

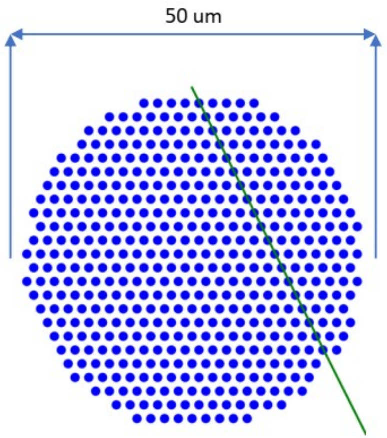




Early Stage Beam Dynamics of Electrons from a Plasmonic Cathode

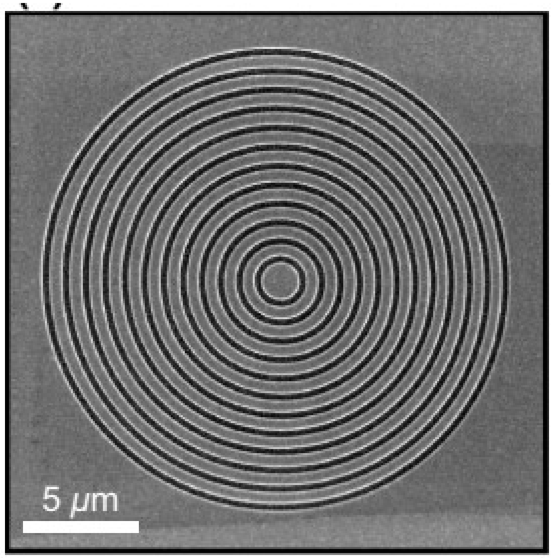
- inhomogeneous electron emission due to local field enhancement by plasmons
- increased transverse momenta (initial emittance) due to cathode geometry
- modification of the RF extraction field due to cathode geometry
- interaction of electrons with plasmon/laser field ?
- single photon vs multi photon emission?
- effects of the finite patch size?

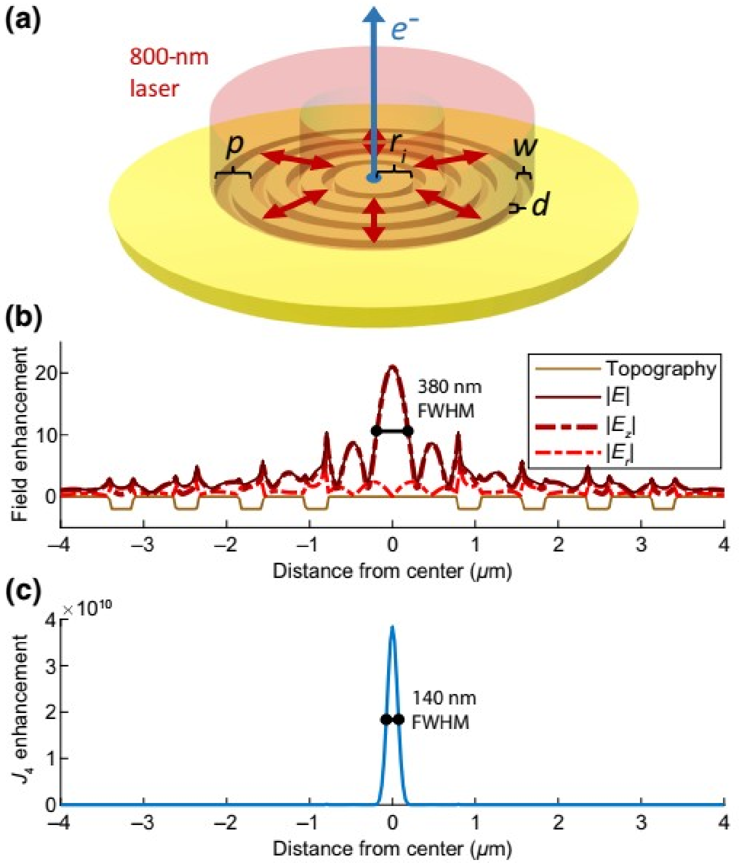


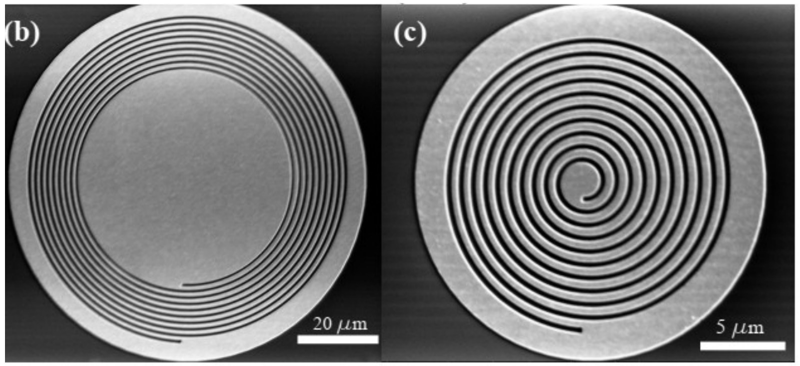


A. Luenagaramwong et al. 'Numerical simulations of early-stage dynamics of electron bunches emitted from plasmonic photocathodes', NIM A 865 (2017).

Outlook: Plasmonic Lens Cathode for 3 GHz Operation?







D. B. Durham et al. ‚Plasmonic lenses for tunable ultrafast electron emitters at the nanoscale', Physical Review Applied 12, 054057 (2019).

A. Kachwala et al. 'Study of nano-structured electron sources using photoemission electron microscope' IPAC 23, (2023).


Thank you for your attention !