Update on the meta-cathode; structuring the cathode surface to enhance and linearize the applied field; and a grating cathode with high QE at threshold

2021 P3 Workshop
SLAC

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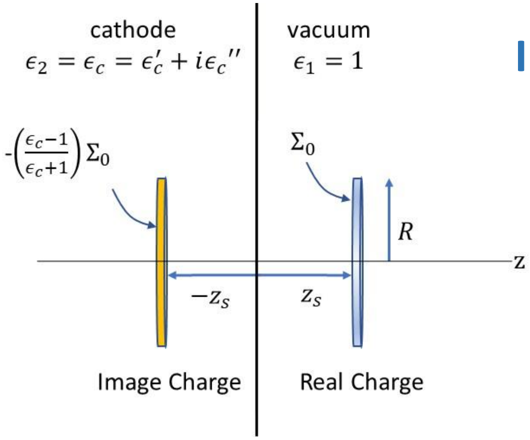
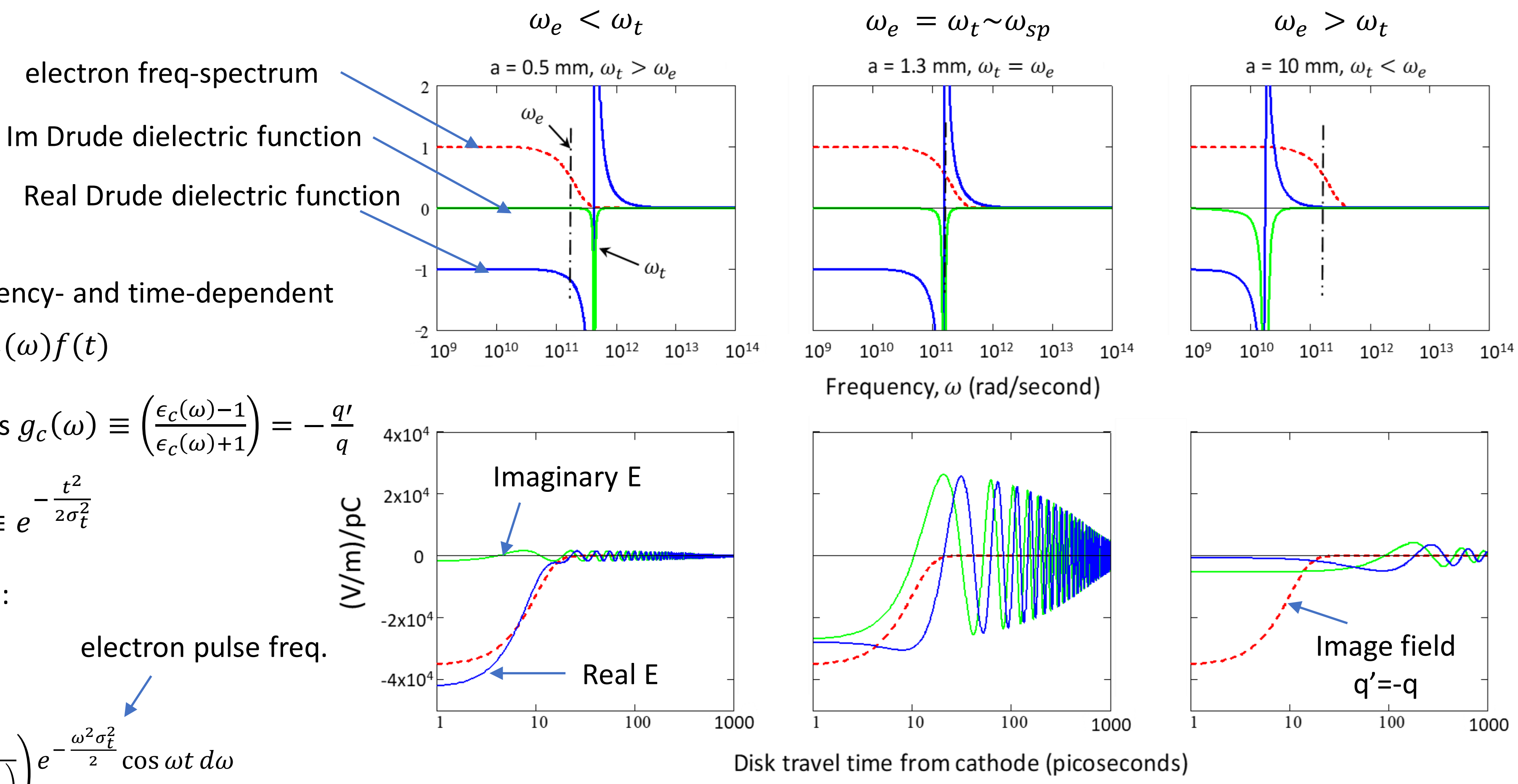
Image field for a responsive cathode with a time-dependent complex dielectric constant





The image field is the product of frequency- and time-dependent functions, $E_{image}^{gaussian}(\omega, t) = \frac{Q_0}{\epsilon_0 \pi R^2}\, g_c(\omega) f(t)$

The surface loss function for the cathode is $g_c(\omega) \equiv \left(\frac{\epsilon_c(\omega)-1}{\epsilon_c(\omega)+1}\right) = -\frac{q'}{q}$

and the field shape function is $f(t) \equiv e^{-\frac{t^2}{2\sigma_t^2}}$

Fourier transform from frequency to time:

Drude model — electron pulse freq.

$$\mathcal{E}_{image}^{gaussian}(t) = -\sqrt{\frac{2}{\pi}}\frac{Q_0}{\epsilon_0 \pi R^2}\sigma_t \int_0^\infty \left(\frac{\omega_p^2}{\omega_p^2 - 2\omega\left(\omega + \frac{i}{\tau_p}\right)}\right) e^{-\frac{\omega^2\sigma_t^2}{2}} \cos \omega t \, d\omega$$

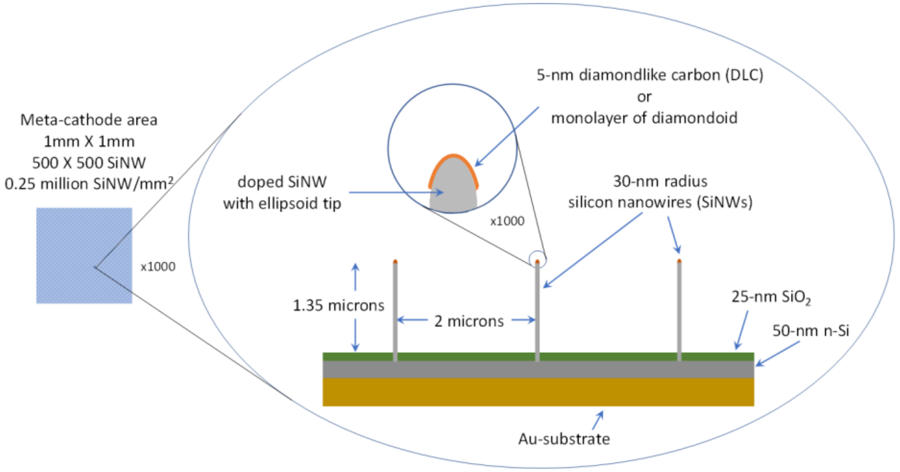
$$\phi_{Schottky} = -\sqrt{\frac{eE_a}{4\pi\epsilon_0}\left(\frac{\epsilon_c - 1}{\epsilon_c + 1}\right)} = -\sqrt{\frac{eE_a}{4\pi\epsilon_0} g_c(\omega)}$$

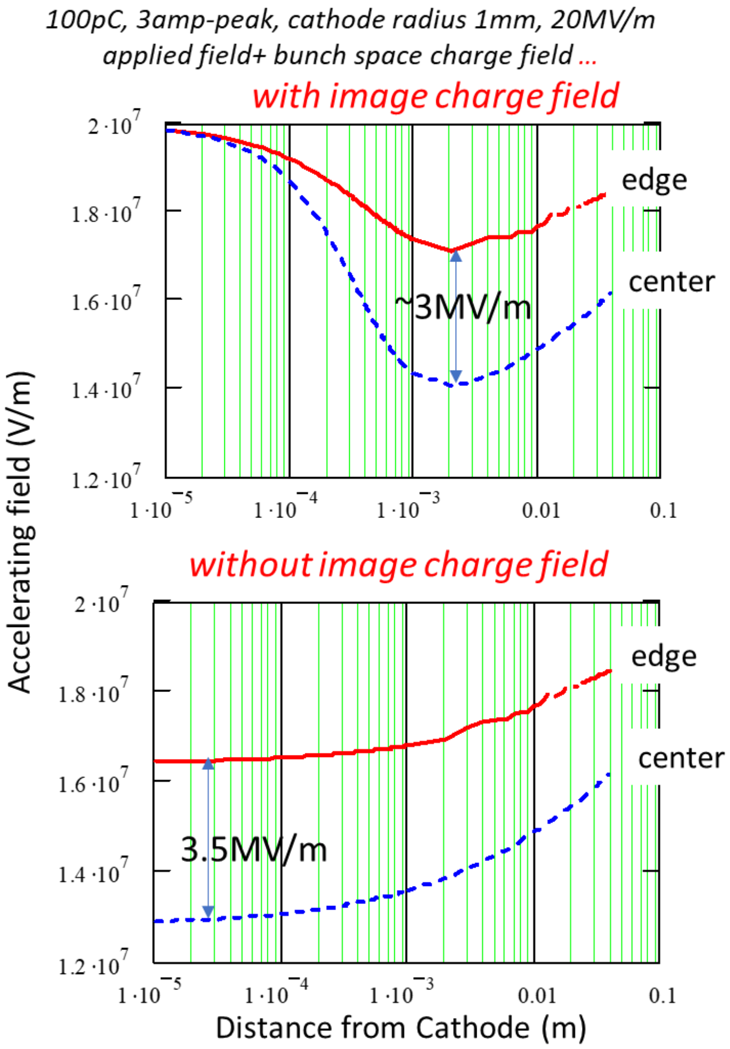
The relative permittivity of most cathode materials is large compared to 1, therefore $g_c \approx 1$ and the eqn. reverts to the usual expression for the Schottky potential of a single electron.

Upper plots: The image-charge field frequency spectrum normalized at ω=0, and the real and imaginary parts of the surface loss function.
Lower plots: The image-charge field/pC at the disk center.

Total fields near the cathode surface: image + space charge + applied

The topological cathode* increases (slightly) the emittance, lowers the cathode's surface field and eliminates Schottky enhancement of the QE. Thus, there are no advantages worth the difficulty of making such a cathode.





The top plot shows the accelerating field vs. distance from the cathode surface for the standard case of a metal cathode with an image charge.

- The image charge field cancels the space-charge field of the real disk charge when the disk is less than 100 microns from the surface. cathode surface field approaches that of the applied field, 20MV/m.
- And the difference between the edge and center accelerating fields also is small close to the cathode, <100microns.

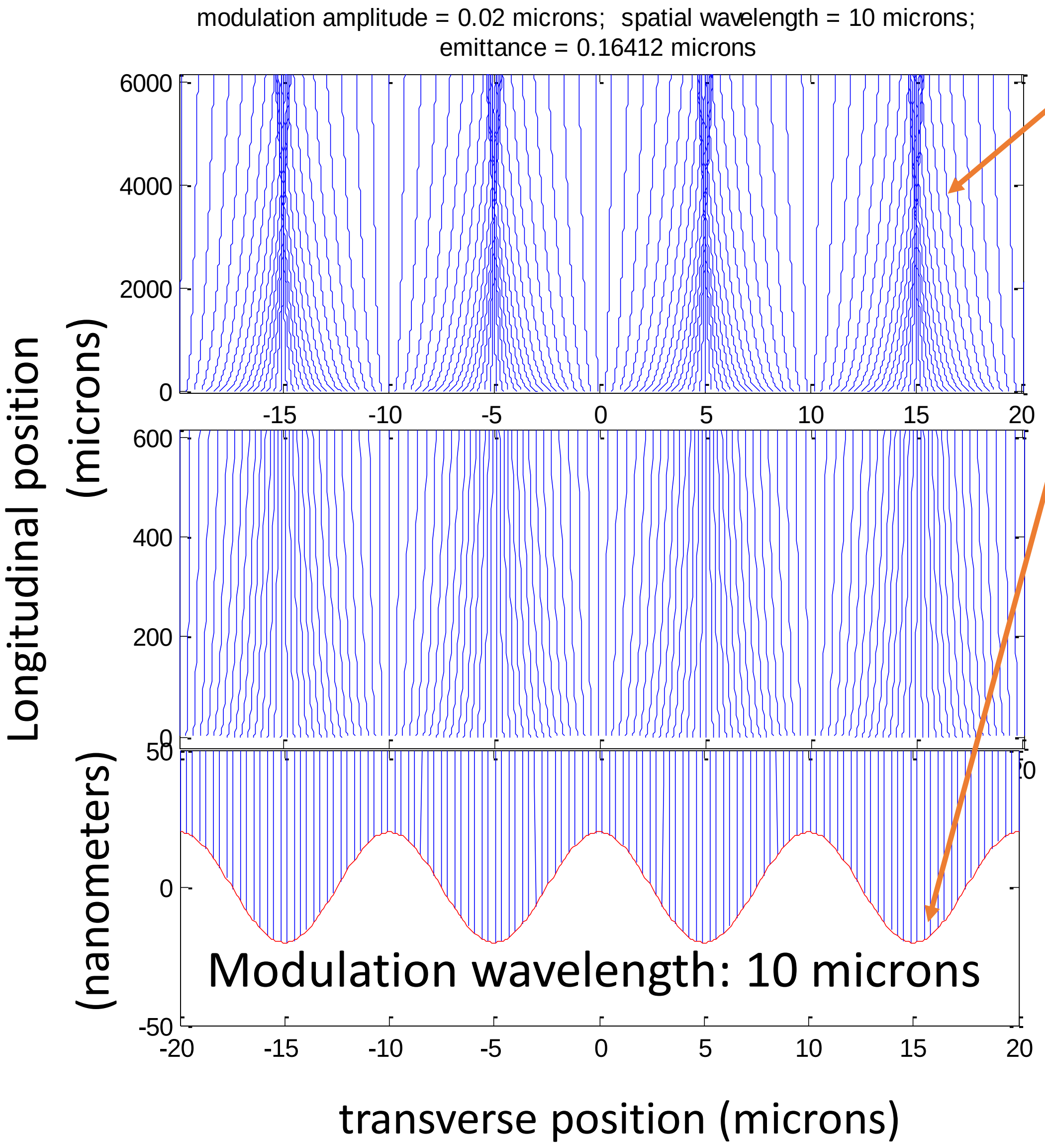
The lower plot shows the total accelerating field if the image field is removed by a meta-cathode.

- In this case, the disk space-charge field is not canceled by image fields and the cathode surface field is reduced by ~7MV/m below the applied field.
- The edge-center accelerating fields is large near the cathode surface for <100microns.

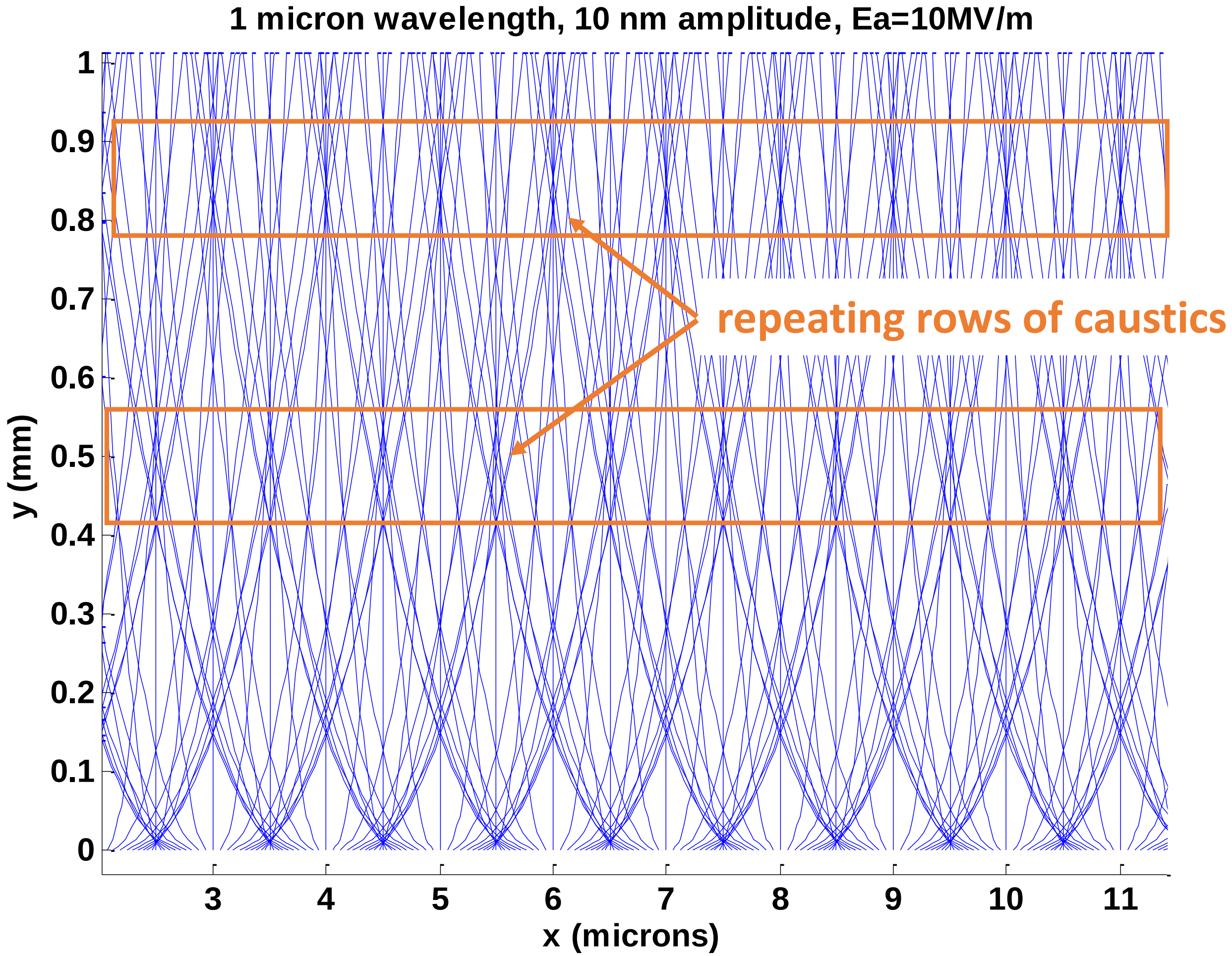
*D.H. Dowell, Physical Review Accelerators and Beams 22, 084201 (2019)

Transverse charge density caustics due to sinusoidal surface modulation

Electrons cross over a few mm from the cathode for applied fields of 50 MV/m.



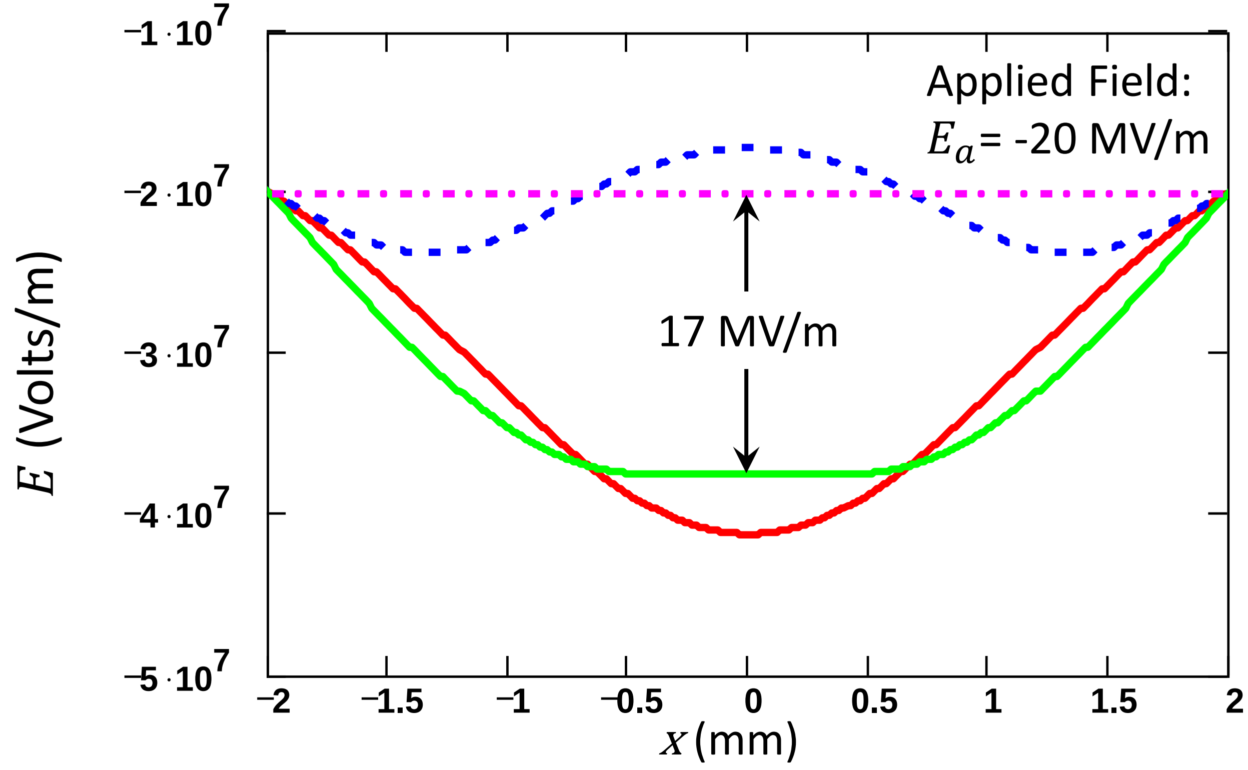
Caustics occur at crossings of the rays forming a line of caustic points. Each high-density spot comes from a trough along the sinusoidal surface=>surface roughness +SC emittances



Adding a spatial third harmonic flattens the enhanced field at the hilltops where the cathode is located, and the electrons are launched from.

The enhanced, flat field region is 1.85-times the applied field, but extends only 1/k in z.
Fundamental extends 1/785=1.3mm, 3rd harmonic extends 1/2356=0.42mm

The 20 MV/m applied field is enhanced a factor of 1.85 to 37 MV/m.
The field is flat over the photocathode's 1 mm diameter area.

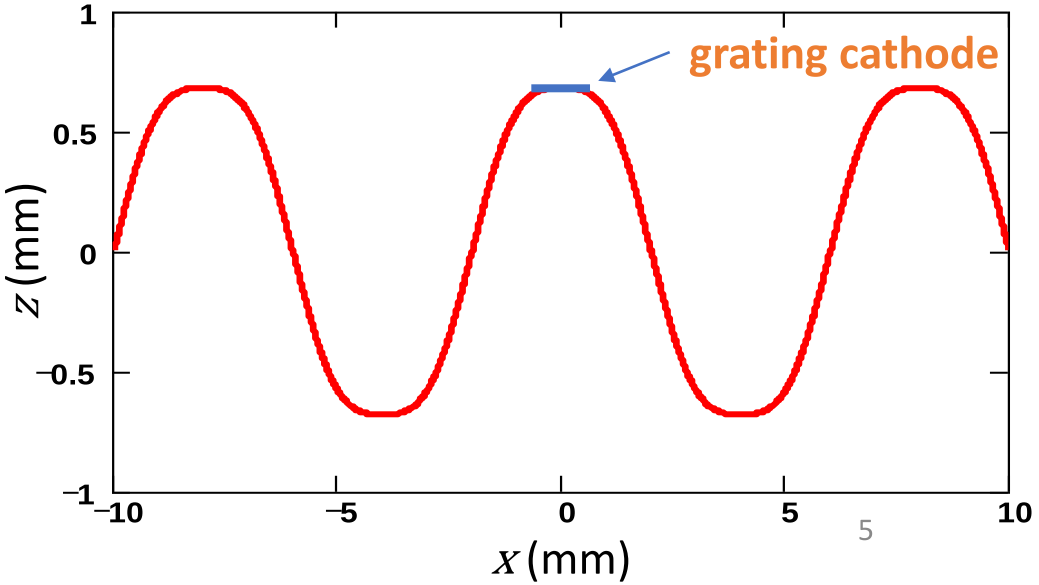


reentrant mini-nosecone design

Surface Parameters:

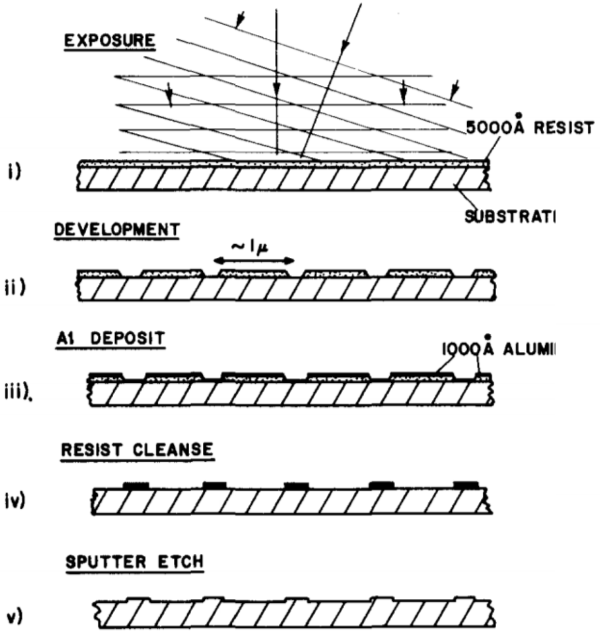
λ_1= 8 mm	λ_3= 2.67 mm
a_1= 0.750 mm	a_3= -0.068 mm
k_1= 785/m	$k_3 = 3k_1$ = 2356/m
a_1k_1=0.59	a_3k_3=0.16

$$a_1 \cos k_1 x + a_3 \cos k_3 x$$

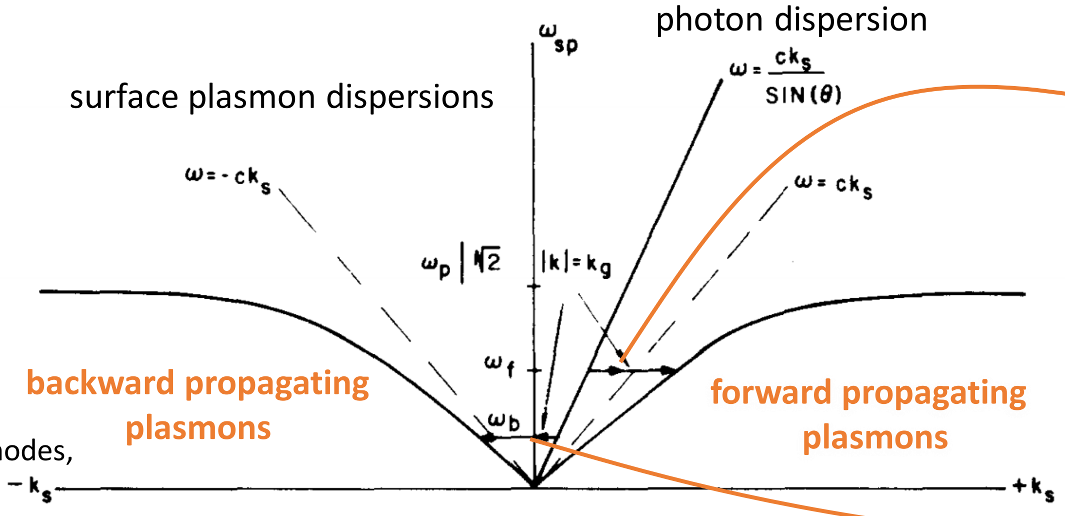


Grating Tuned Photocathodes* give high QE at photothreshold + low emittance(?)

- Tune/Adjust the grating spacing to generate backward propagating surface plasmons at a wavelength near photoemission threshold.
- Coat the grating with a ~50nm layer of a low work function material like Cs_2Te, K_2CsSb, Ag-O-Cs,…
- Photoemission at the backward propagating plasmon wavelength will have high-QE due to the plasmon excitation (higher absorption) and the low work function of the coating as shown in Endriz and Spicer papers.
- The MTE can be made very small by operating close to threshold and the cathode grating tuned for high QE at threshold.
- The MTE/intrinsic emittance has not been measured for this type of cathode. Any volunteers?

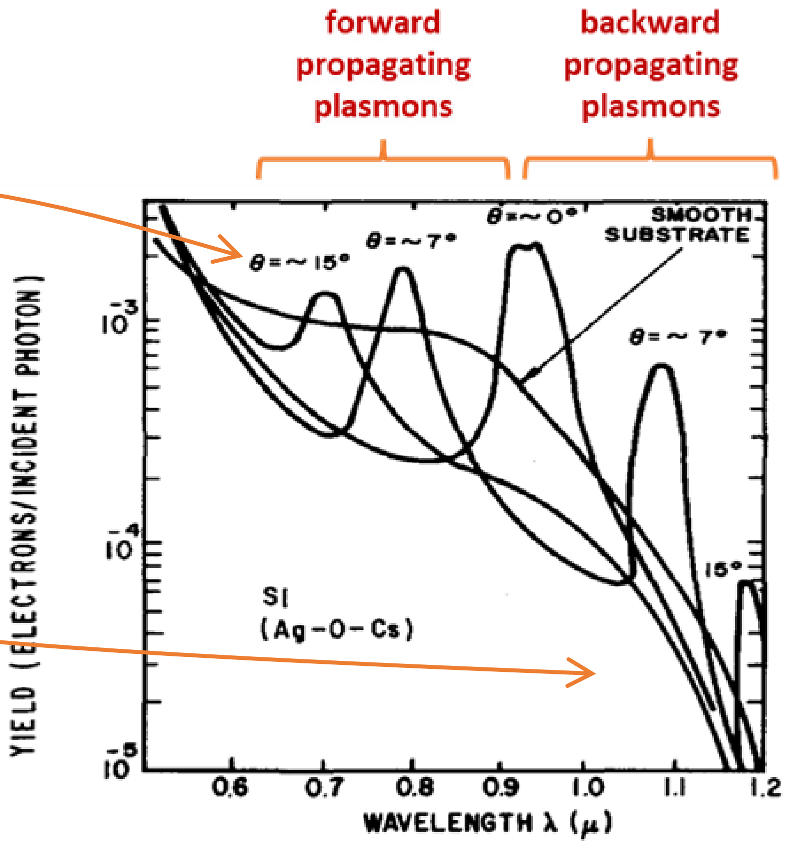


$$\epsilon_{intrinsic} = \sigma_x \sqrt{\frac{\hbar\omega - \phi_W}{3mc^2}}$$



anomalous QE vs. $\hbar\omega$ behavior near plasmon energies: tune angle such that QE increases with decreasing photon energy near threshold

Angle-of-incidence tuning of the QE peak wavelength



*Surface waves and grating tuned photocathodes, J.G. Endriz, Appl. Phys. Lett. 25,261(1974) https://doi.org/10.1063/1.1655463

J.G. Endriz and W.E. Spicer, "Surface-plasmon-on electron decay and its observation in photoemis Phys. Rev. Lett. **24**, 64(1969)

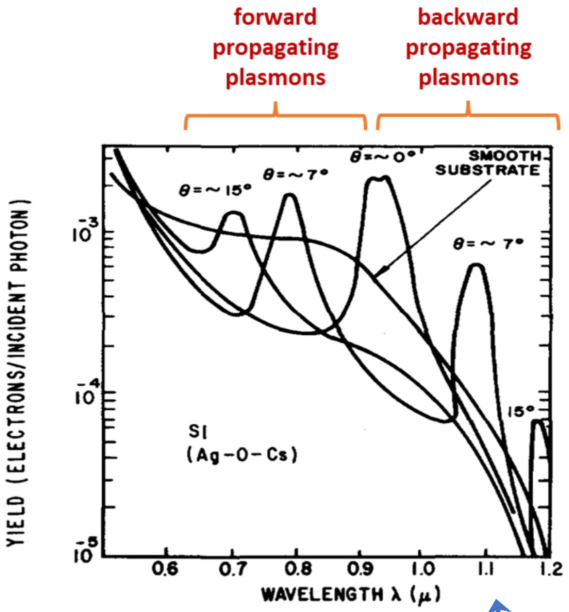
Thank you for your attention!

❖ Endriz's Grating Tuned Cathode with high QE at photoelectron threshold

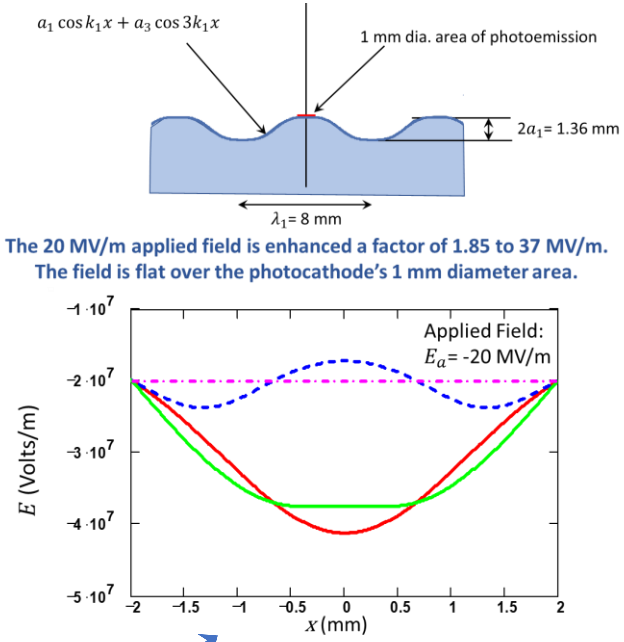
❖ Structured/reentrant cathode surface to enhance and linearize the applied field at the cathode surface

❖ Meta-cathode update

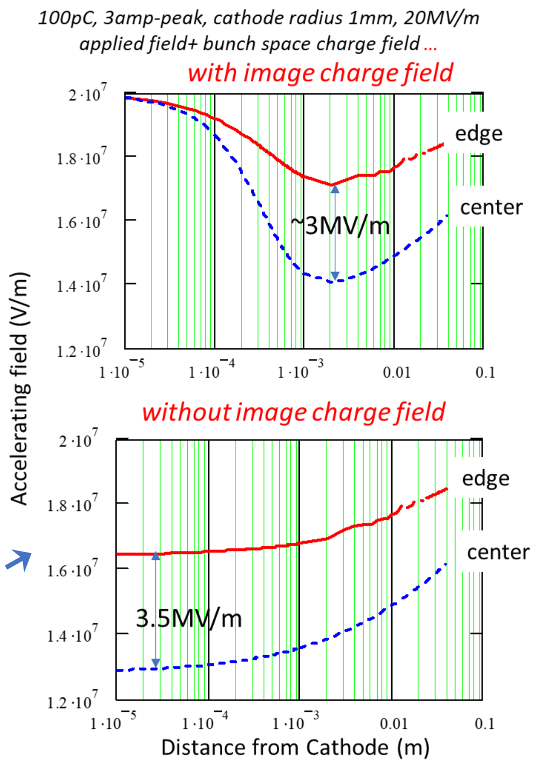
Grating tuned cathodes give high QE at photo threshold*

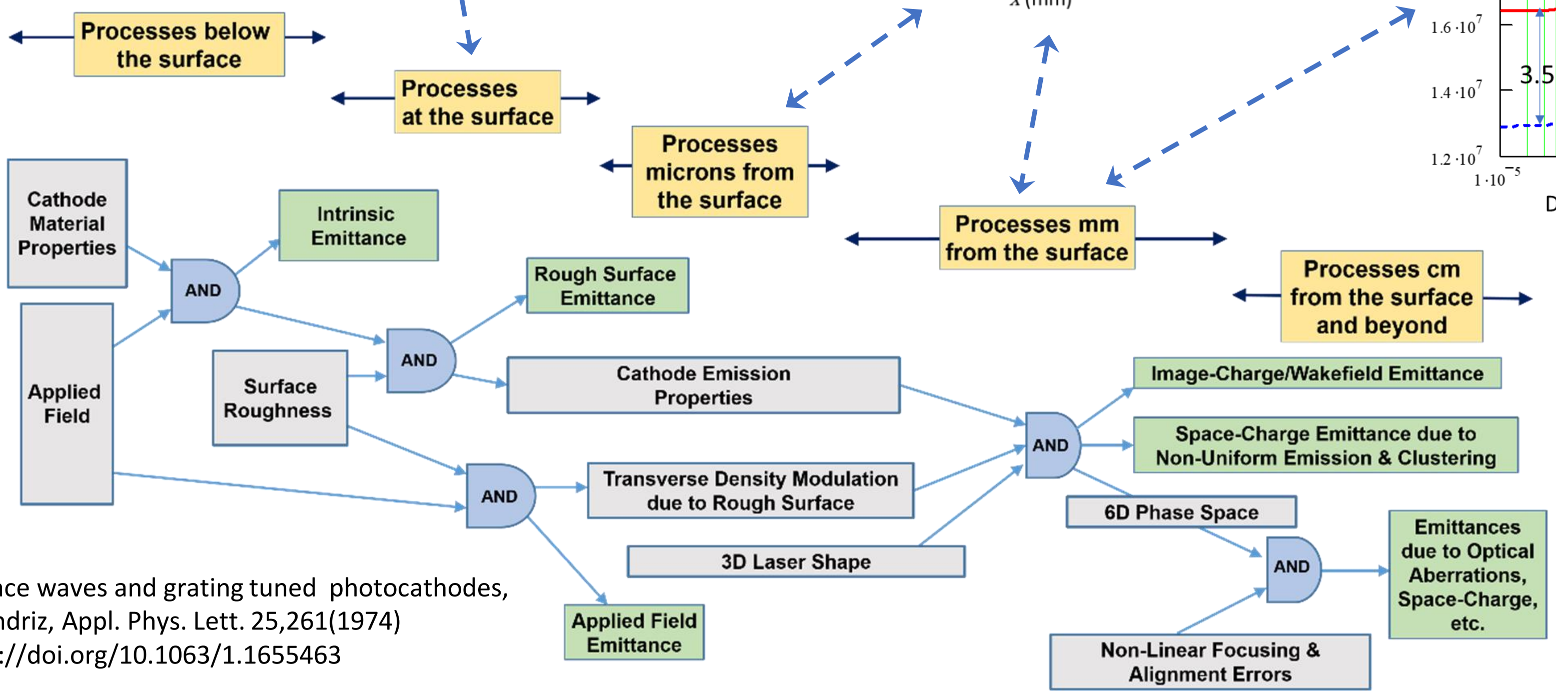


Adding a spatial third harmonic flattens the enhanced field at the hilltops where the cathode is located



Meta-cathode doesn't improve beam quality





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