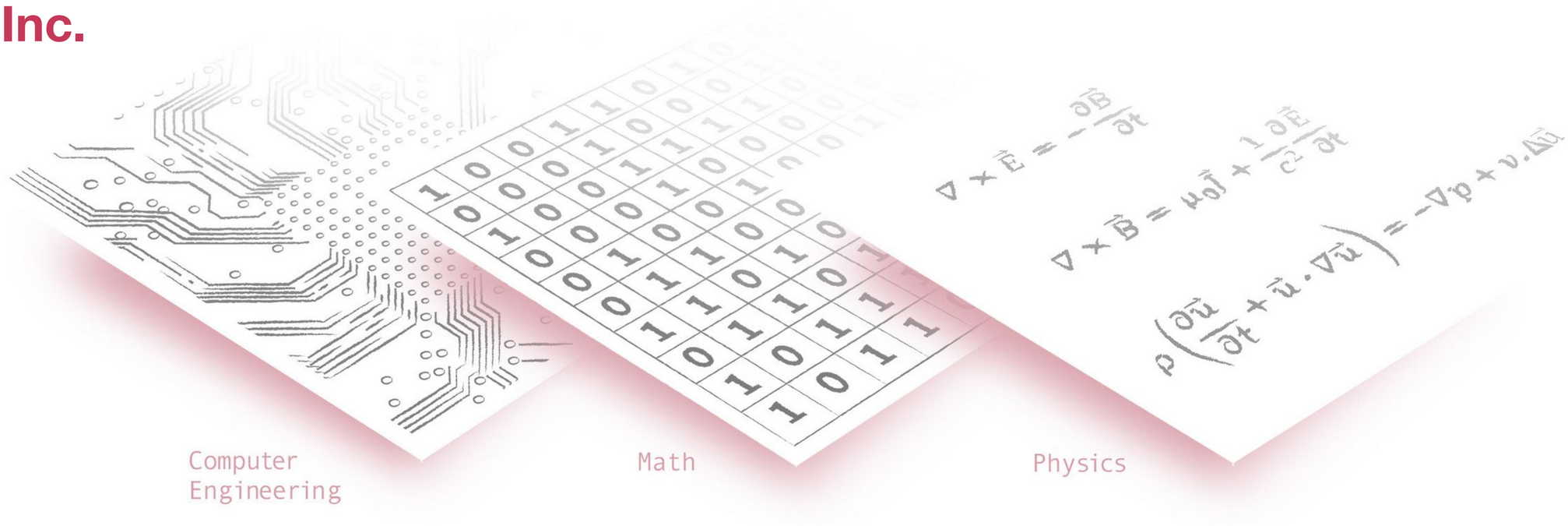
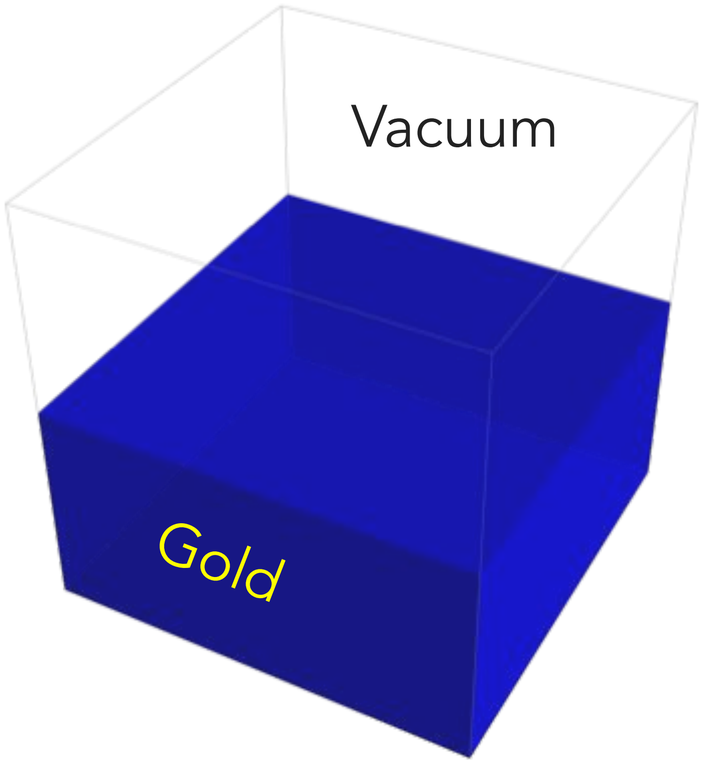
INTRO TO FDTD (5)

Flexcompute **Inc.**



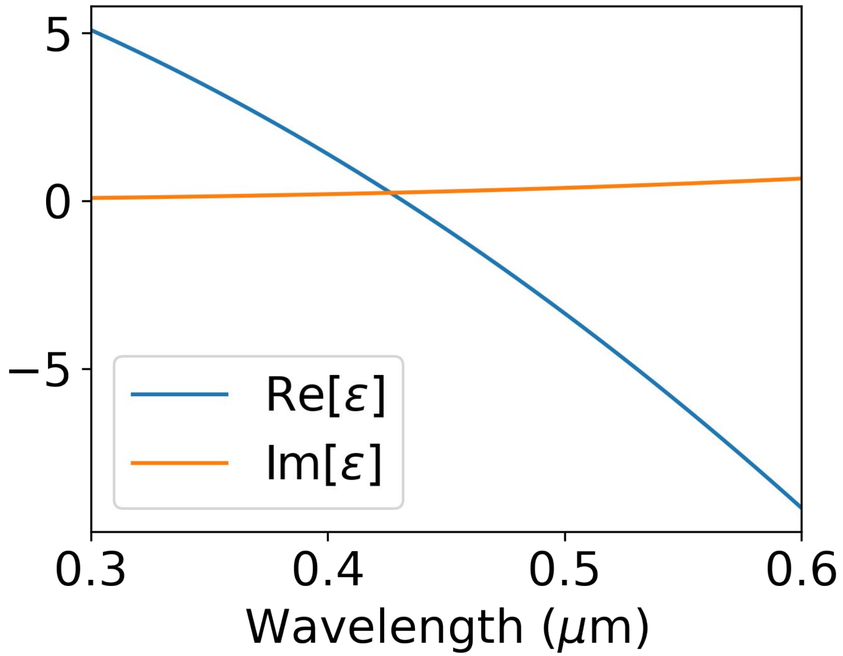
Tidy3D

Material dispersion is common

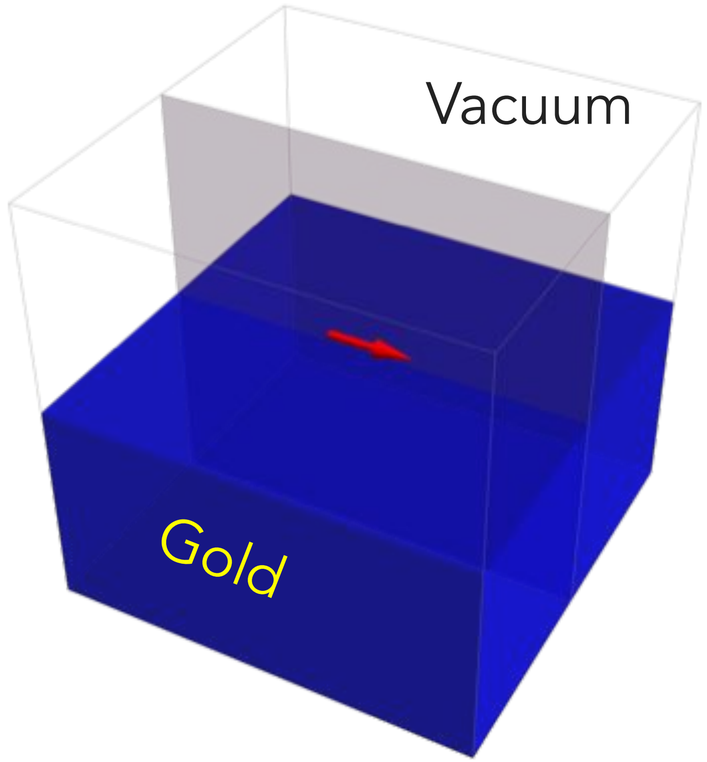


Gold dispersion with Drude model

$$\varepsilon(\omega) = \varepsilon_\infty - \frac{\omega_p^2}{\omega^2 + i\omega\gamma}$$

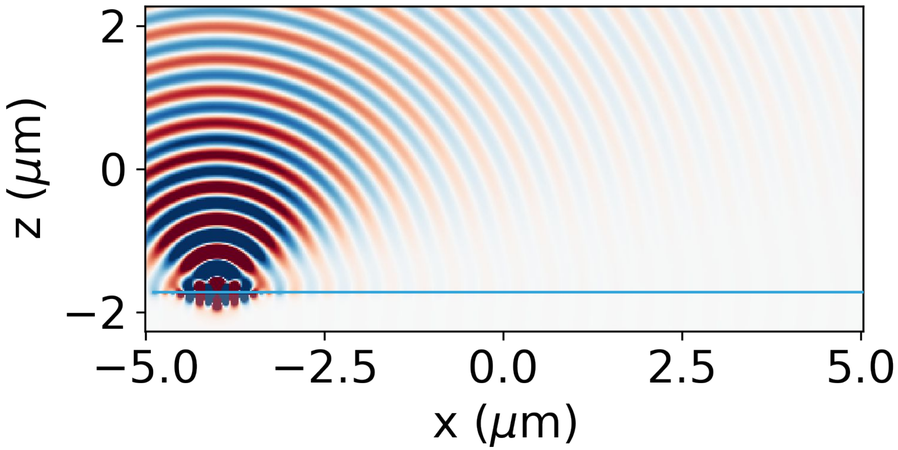


$\varepsilon_\infty = 9.84$, $\omega_p = 9.01$ eV, $\gamma = 0.072$ eV

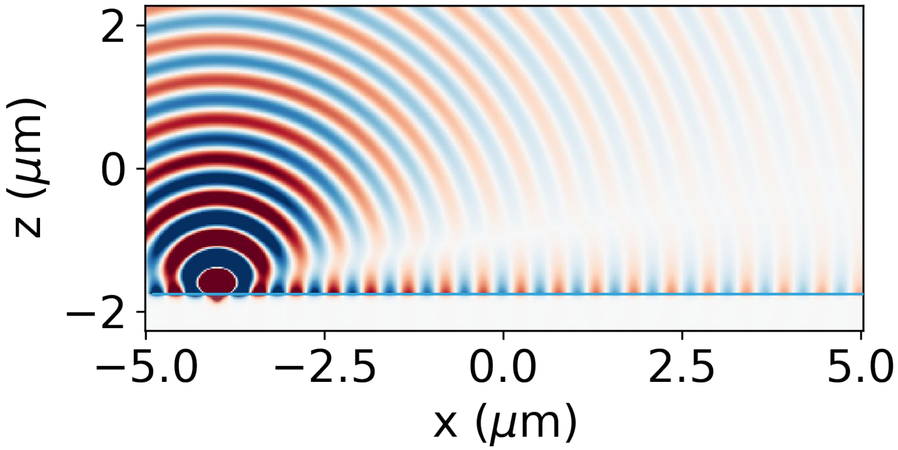


Excite surface plasmonic polariton (SPP) on gold surface

Wavelength 450 nm



Wavelength 550 nm



gold-air interface

Without dispersion:

- $\boldsymbol{D}(t) = \varepsilon\, \boldsymbol{E}(t)$
- The displacement field reacts instantaneously to the applied electric field.

With dispersion:

- In frequency domain: $\boldsymbol{D}(\omega) = \varepsilon(\omega)\, \boldsymbol{E}(\omega)$
- In time domain: $\boldsymbol{D}(t) = \int dt' \epsilon(t - t') \boldsymbol{E}(t')$
- A dispersive material has a "memory". Its displacement field depends on the electric field in the past.

The method of complex-conjugate pole-residue pairs: fit $\epsilon(\omega)$ as:

$$\varepsilon(\omega) = \varepsilon_\infty - \sum_m \left[\frac{c_m}{i\omega + a_m} + \frac{c_m^*}{i\omega + a_m^*}\right]$$

M. Han, R. W. Dutton and S. Fan, IEEE Microwave and Wireless Component Letters, 16, 119 (2006).

EXAMPLE:

For the Drude model

$$\varepsilon(\omega) = \varepsilon_\infty - \frac{\omega_p^2}{\omega^2 + i\omega\gamma}$$

Use two pairs

$$c_1 = \frac{\omega_p^2}{2\gamma}, a_1 = 0 \text{ and } c_2 = -\frac{\omega_p^2}{2\gamma}, a_2 = -\gamma$$

The method of complex-conjugate pole-residue pairs: fit $\epsilon(\omega)$ as:

$$\varepsilon(\omega) = \varepsilon_\infty - \sum_m \left[\frac{c_m}{i\omega + a_m} + \frac{c_m^*}{i\omega + a_m^*}\right]$$

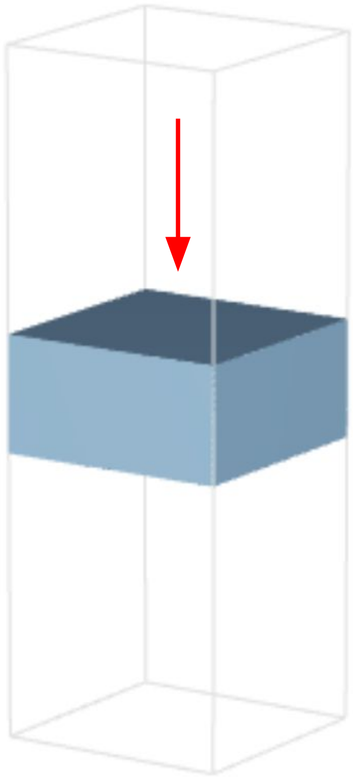
Auxiliary differential equation

$$\frac{d}{dt}\boldsymbol{J}_m(t) - a_m\boldsymbol{J_m}(t) = \varepsilon_0 c_m \frac{d}{dt}\boldsymbol{E}(t)$$

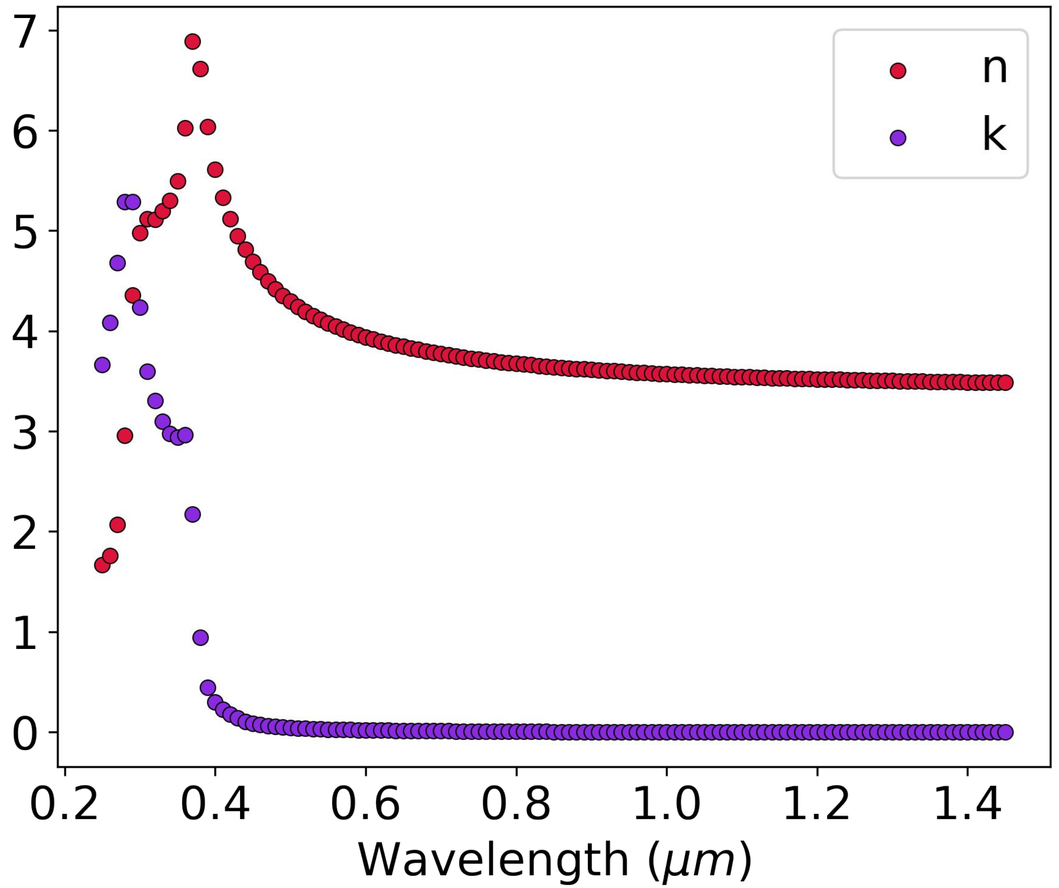
Computational cost increases with the number of poles.

M. Han, R. W. Dutton and S. Fan, IEEE Microwave and Wireless Component Letters, 16, 119 (2006).

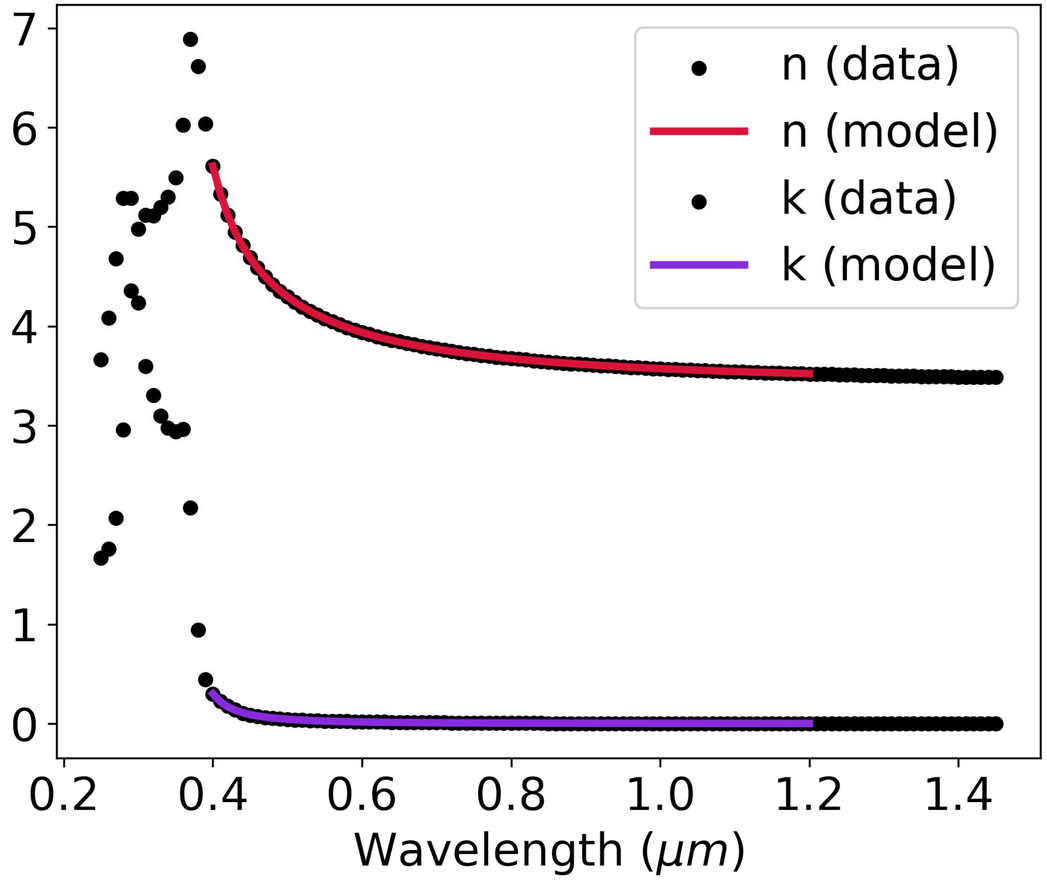
Crystalline silicon slab transmission



Dispersion data [Green, 2008]

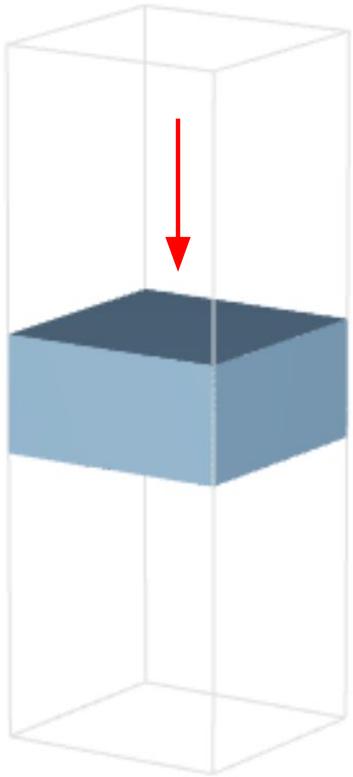


Fit dispersion data with CCPR model in wavelength range [0.4,1.2] μm



- 2 poles for RMS error ~2.6%
- Pole frequency: 0.26μm and 0.35 μm

Broadband transmission computation in a single simulation



Thickness: 1μm