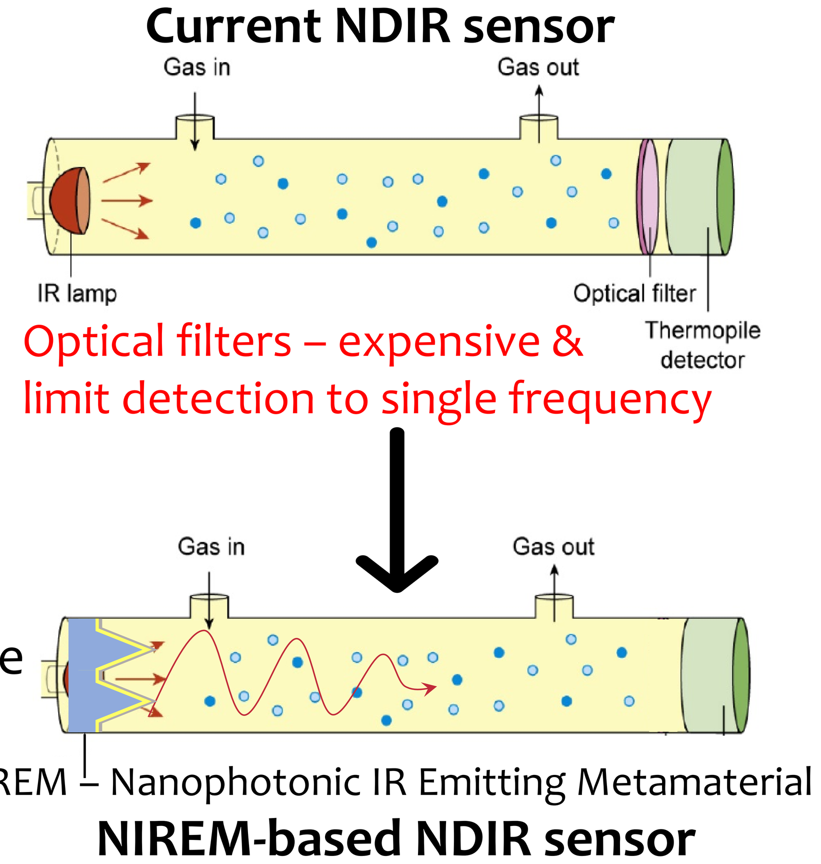
Non-dispersive Infrared (NDIR) Sensing of CO_2 Using CdO Films

Alyssa K. Livingood[1], J. Ryan Nolen[2], Thomas G. Folland[3], Joshua D. Caldwell[3]
[1]Department of Electrical and Computer Engineering, University of Kentucky, Lexington, KY, [2]Interdisciplinary Materials Science Program, Vanderbilt University, Nashville, TN, [3]Department of Mechanical Engineering, Vanderbilt University, Nashville, TN

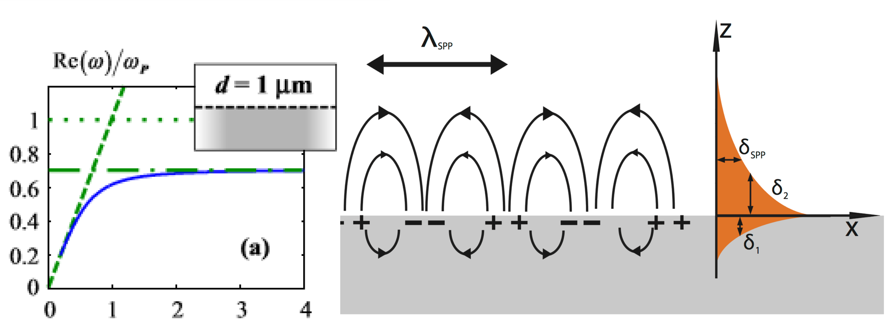
Motivation

- Infrared (IR) spectra provide a 'fingerprint' for chemicals
- Many applications require sensitive detection and identification of gas molecules
- Non-dispersive IR (NDIR) sensors provide current state of the art, but require broadband IR source, optical filter and inexpensive detector



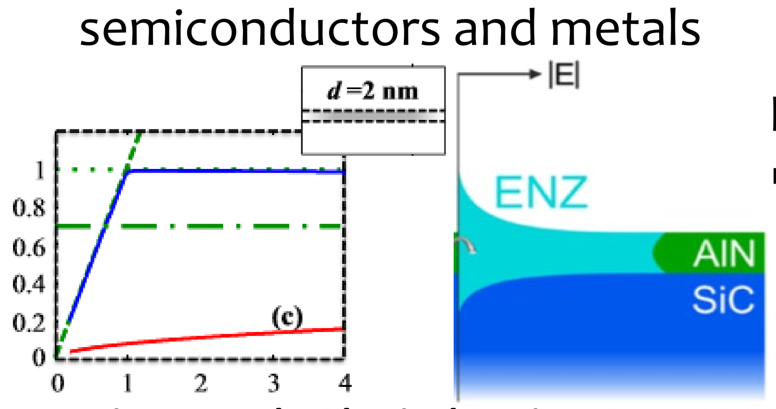
Background

- **Surface plasmons:** Oscillating electrons on the surface of a metal
- **Polaritons:** Coupling of light with an electric dipole



Campione, et al., *Physical Review B* 91, 121408(5)(2015).

- Surface plasmon polaritons (SPPs) supported in highly doped semiconductors and metals

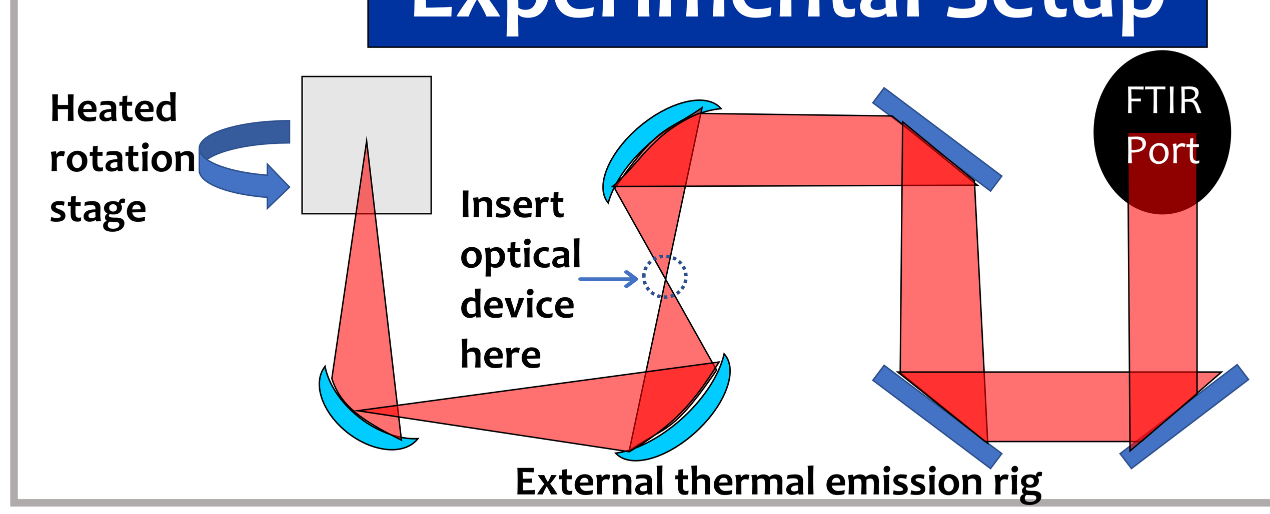


Campione, et al., *Physical Review B* 91, 121408(5)(2015).
Passler, et al., *Nano Letters* 18, 4285-4292(2018).

Epsilon-Near-Zero (ENZ) Modes

- Result from hybridization of SPPs on top and bottom interfaces of thin metallic films
- Offer extreme light confinement within ultrathin films
- Can couple to free-space and occur at frequency where dielectric permittivity crosses through zero
- Potential for tunable, high absorption modes in planar deeply sub-diffractional thickness films

Experimental Setup



Sample

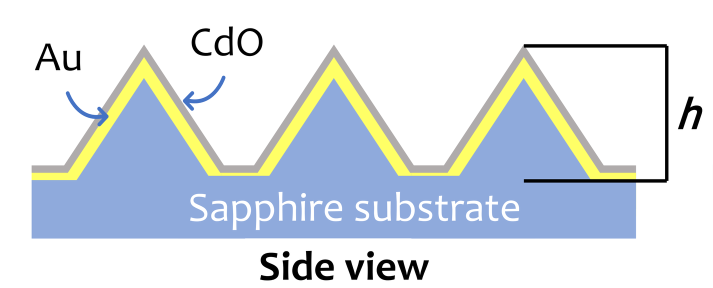
N-Doped CdO Film on Patterned Sapphire Substrate (PSS)

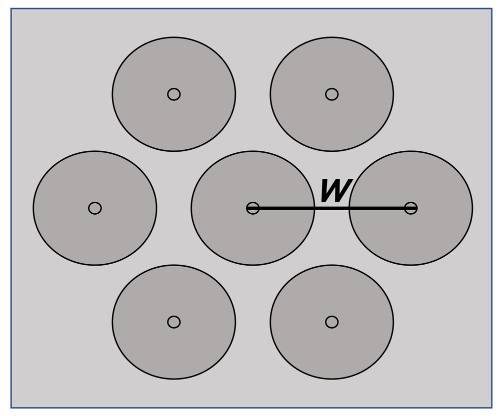
- Benefits of CdO:
  - Low effective mass → large dynamic tuning range SPPs

$$\varepsilon(\omega) = \varepsilon_\infty - \frac{\omega_p^2}{\omega^2 + i\gamma\omega} \qquad \omega_p = \left(\frac{Ne^2}{m^*\varepsilon_0}\right)^{1/2} \qquad \gamma = \frac{e}{\mu m^*}$$

carrier density (N), mobility (μ)

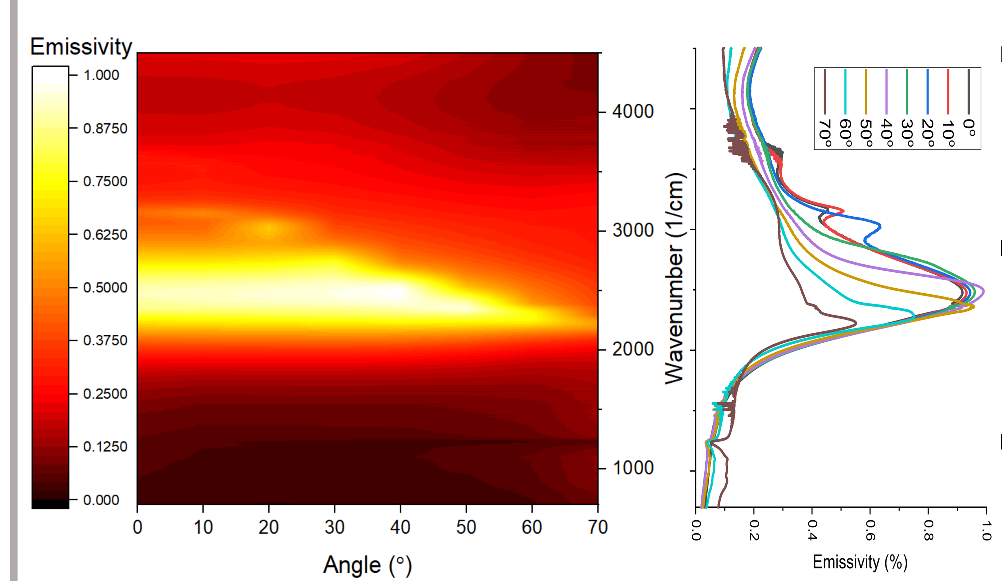
  - High mobility → low losses





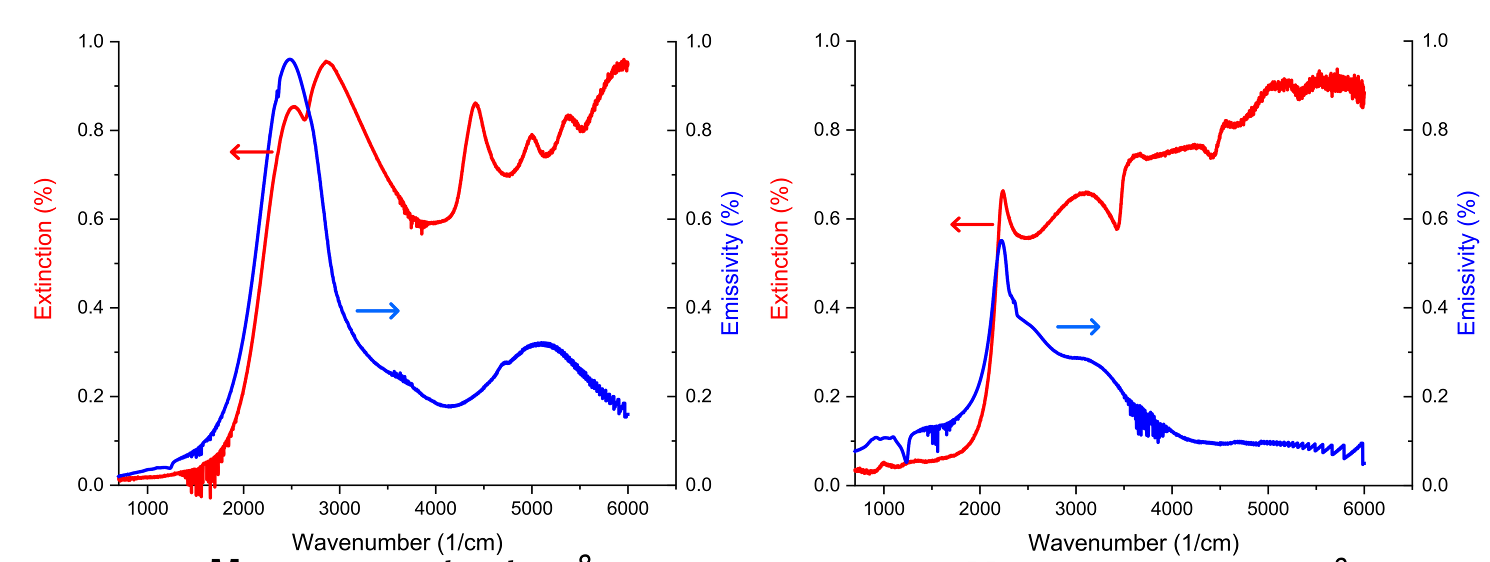
- Cones patterned on substrate in a hexagonal lattice
- Cone height (***h***): 1.58 µm
- Peak-to-peak width (***w***): 3.02 µm
- For calibration need to compare to black body: Vertically aligned carbon nanotubes (VACNT)

Results



Tunability

- Goal: Sample emission at 2500 cm^{-1}
- How? Control carrier concentration of CdO
- Why? Resonant frequency of carbon dioxide



Extinction

- Summation of absorption and scattering
- Found by doing reflectance and transmission measurements
- Why? Kirchoff's law of thermal radiation (emissivity = absorptivity)

$$1 = T + R + A + S$$

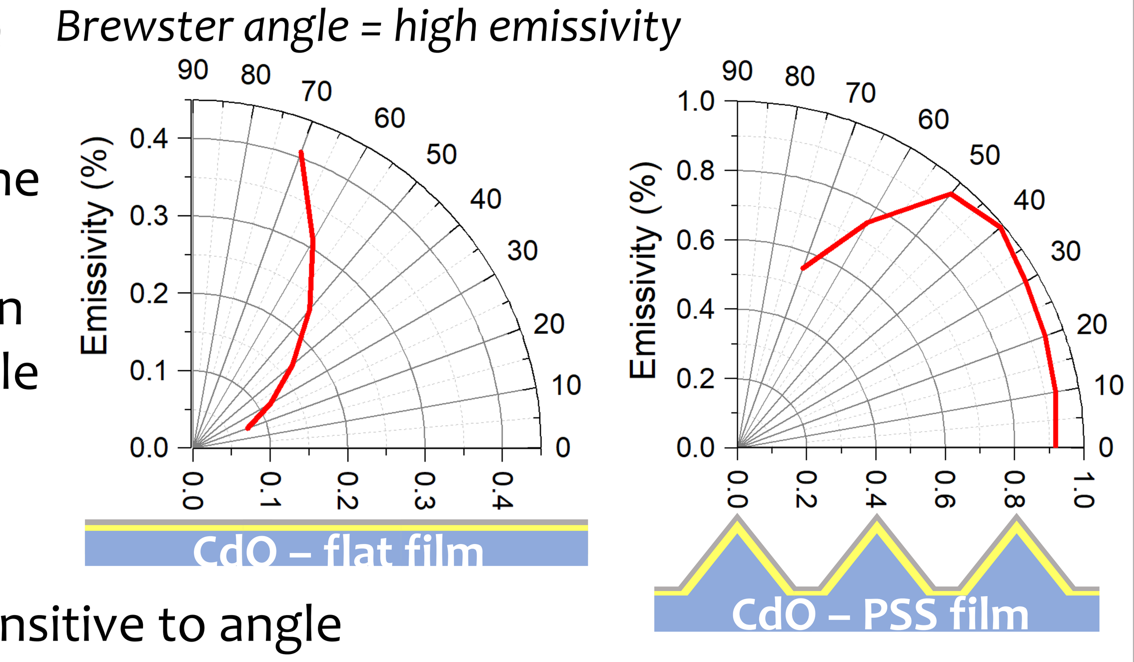
T = 0; R: Measured; A + S: Extinction

Results

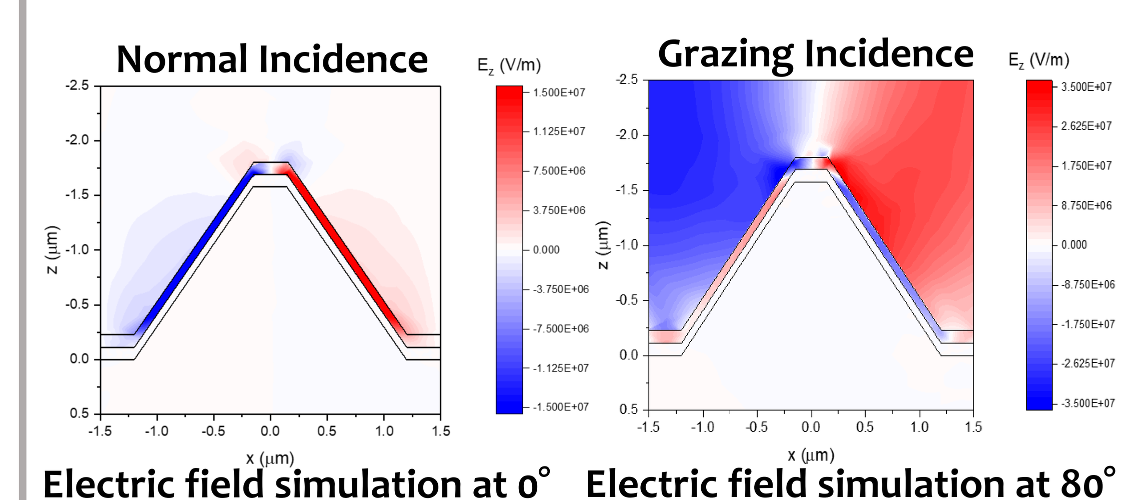
Angle Dependence

Brewster angle = high emissivity

- For flat films:
  - P light excites the ENZ mode
  - Highest emission at Brewster angle

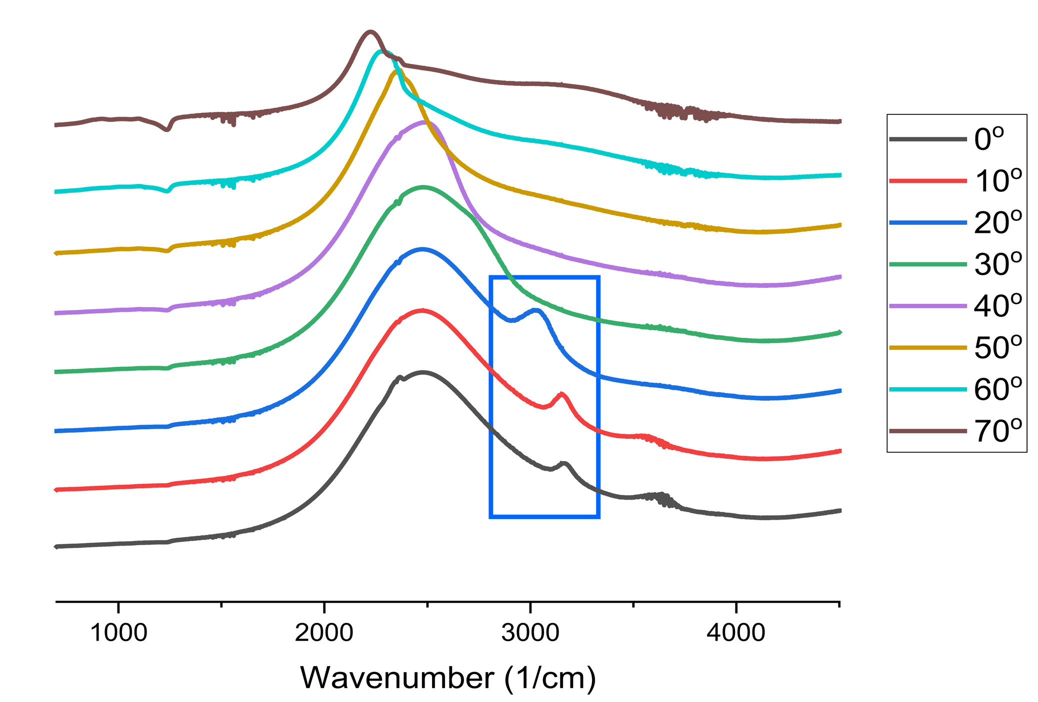


- For PSS films:
  - Emission is insensitive to angle
  - Strong emissivity at normal incidence

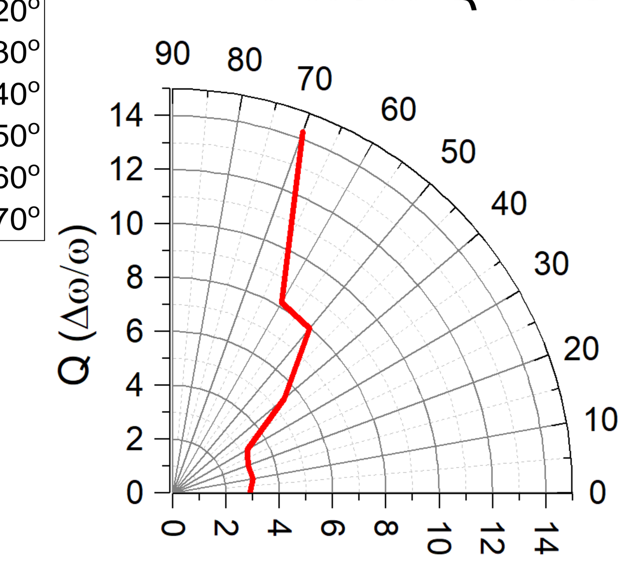


Fano Interference

- Interference between localized and propagating modes
- Causes asymmetric line shape
- Why does this help?
  - Narrow-band thermal emission
  - Increased Q factor



Box highlights propagating mode



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