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Resonant Dust: IR Targets for Tagging Tracking, and Identification

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Outline of Talk

- Introduction IR tags
- IR thermographic phosphors
- IR read out of microcantilevers
- Customized IR resonant surfaces (smart dust)
- Enabling hardware developments in the LWIR
- Future areas of interest (smarter tags)

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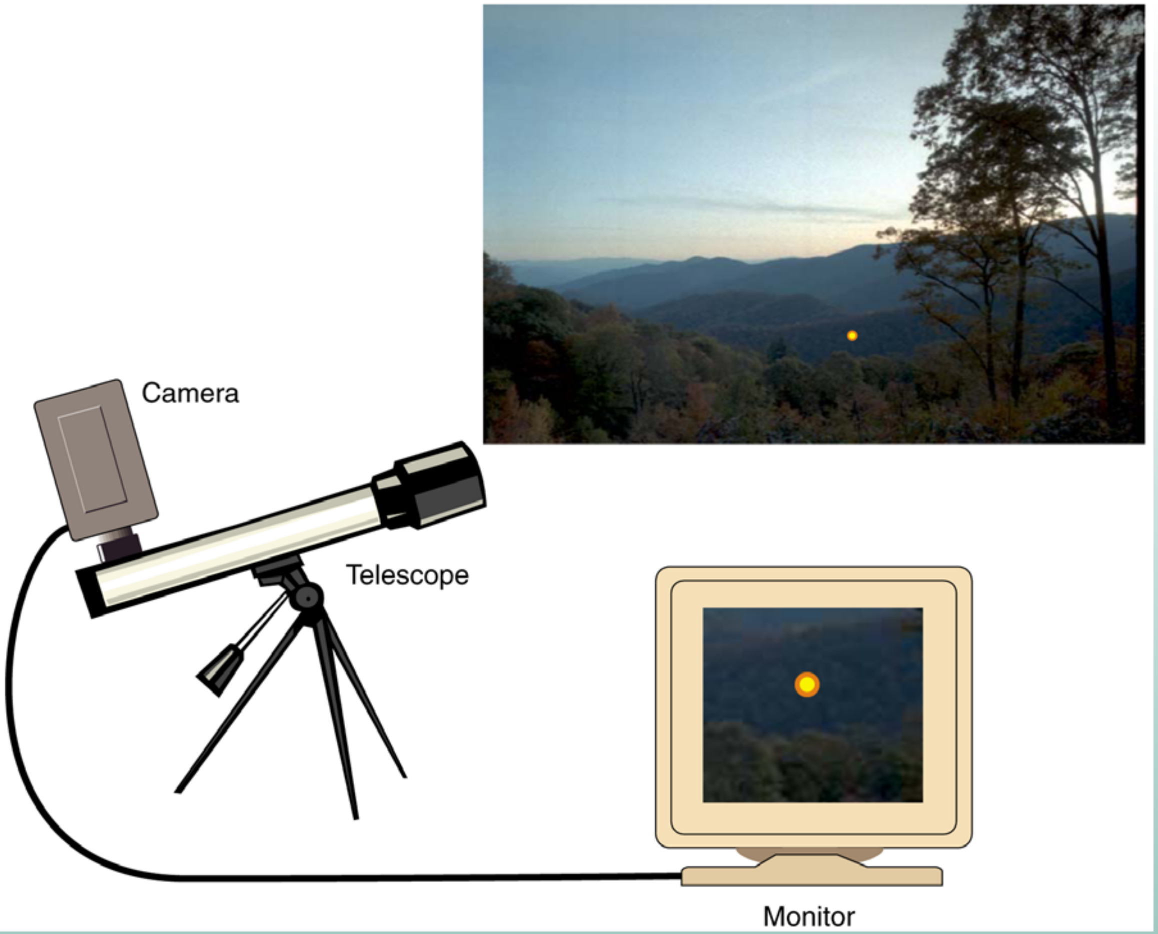
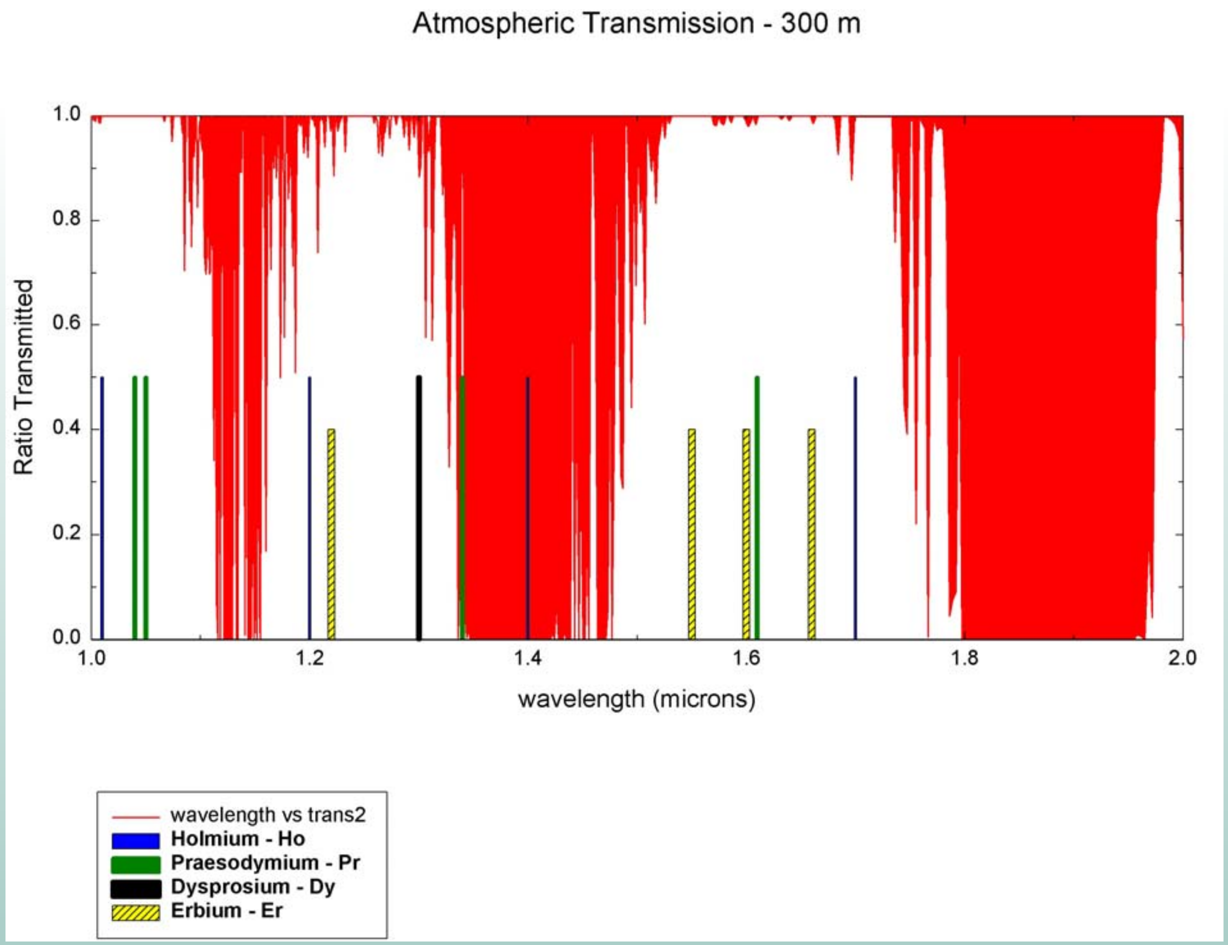
Infrared (IR) Thermophosphor Paint Ball Detectable at >1 Km

ORNL 99-1351C EFG

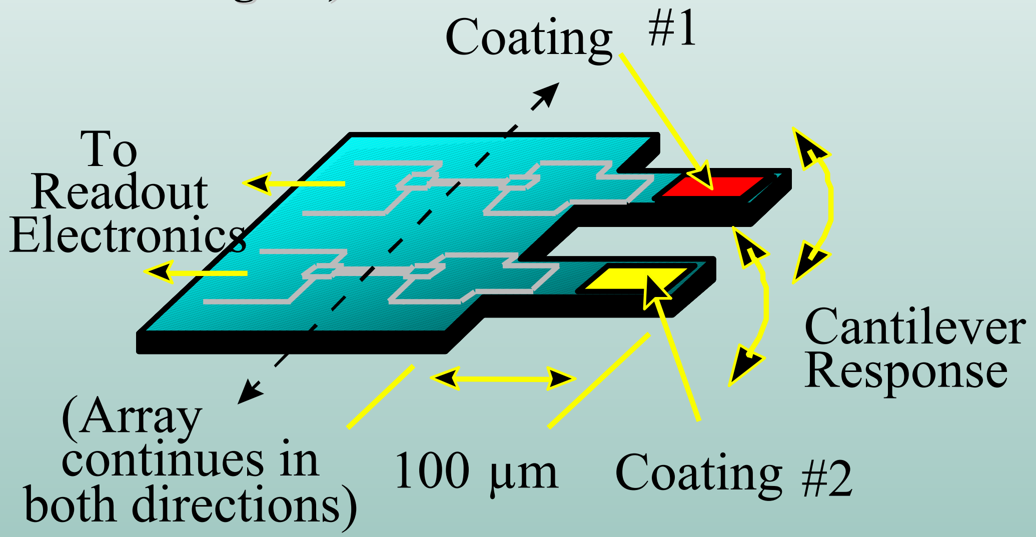


IR Phosphors Are Available in Atmospheric Windows

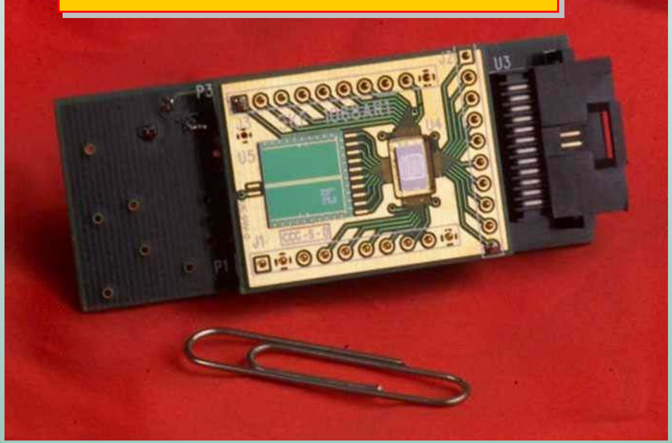


Electrically Readable Cantilevers R&D at ORNL

- ORNL presently has several patents issued and pending and over a dozen disclosures on the technology
- Utilizing *arrays* of microcantilevers on a *single chip* with *customized coatings* to produce application-specific programmable sensors
- Researching the limits of electronic readout of microcantilevers
- Researching different chemical coatings for selective sensing (chemical & biological)

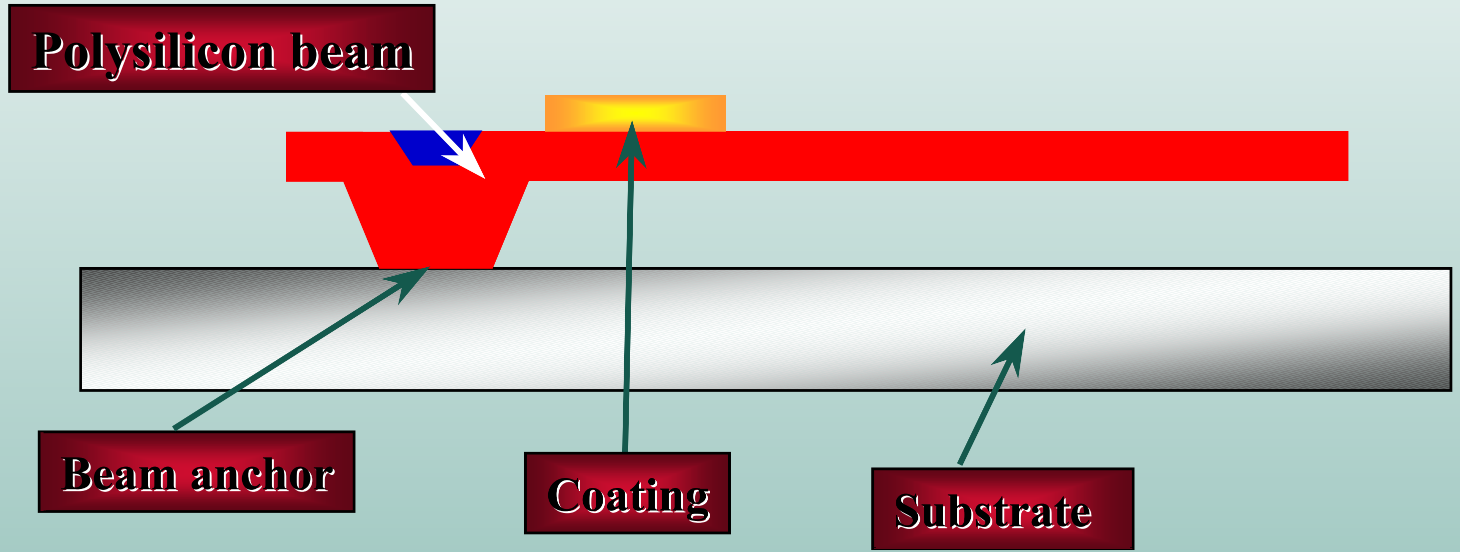


ORNL-developed cantilever array



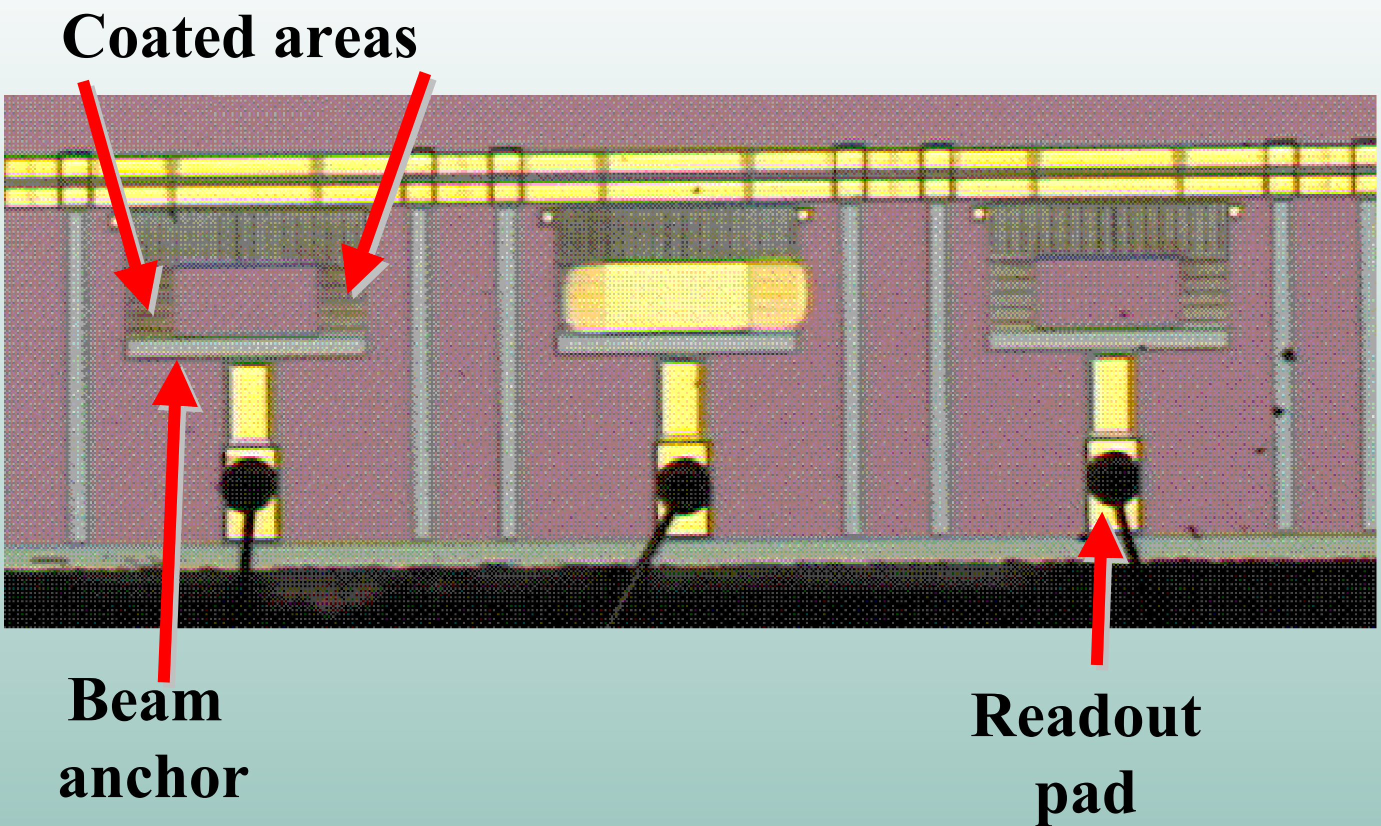
ORNL surface micromachined cantilever cross-section fabbed through MUMPS

+ Exposed coatings can have two basic effects
  - Φ Change in mass (resonant frequency change)
  - Φ Change in stress (positional change)



Our basic cantilever design is a Π-shaped structure

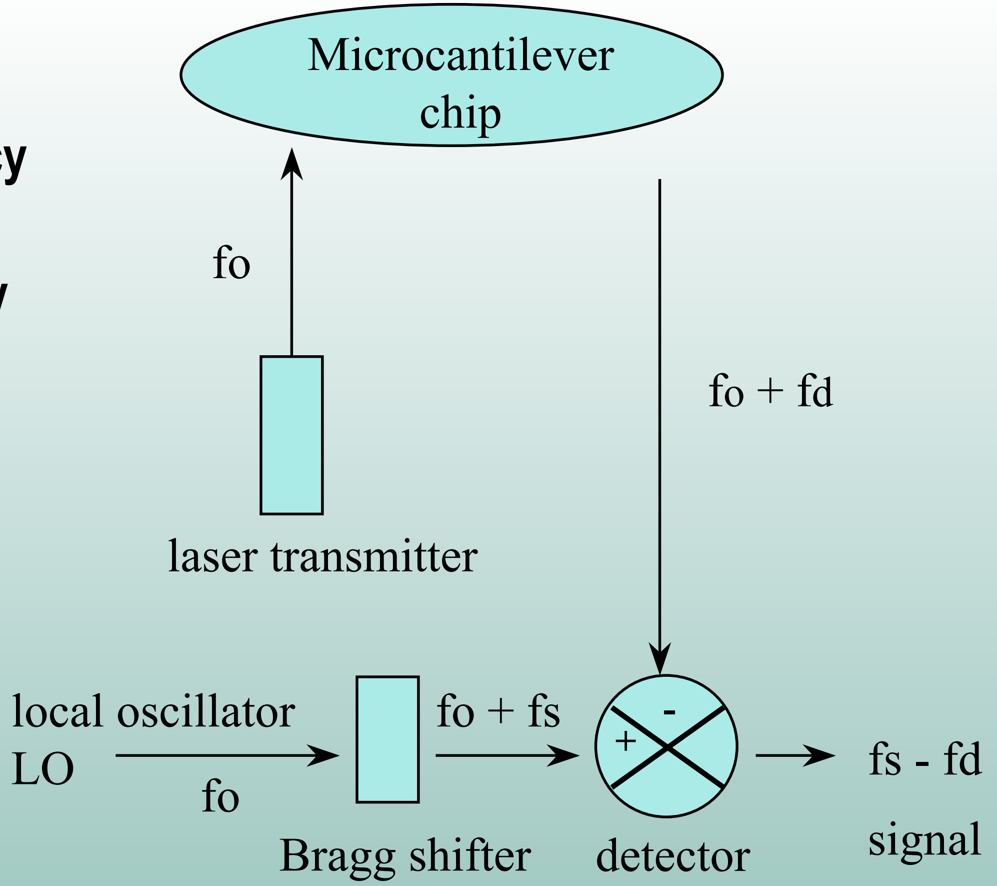
- The coating area beam width is approximately 100 μm



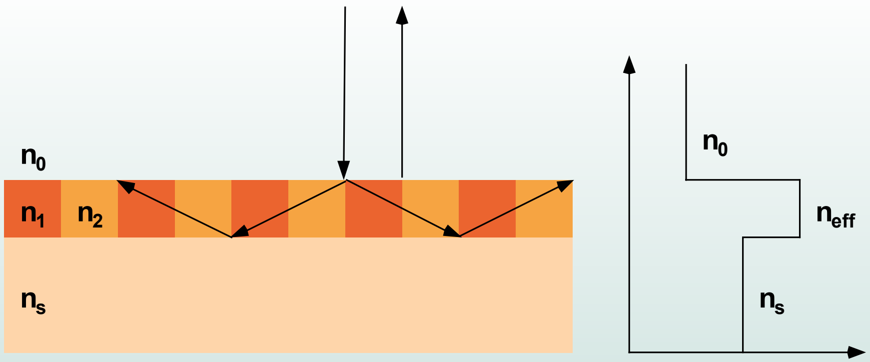
Long Wave IR Remote Readout of Vibrating Microcantilevers at > 1 Km Using Doppler Shift

- Shift proportional to frequency of microcantilever vibration
- Data transferred by frequency modulation

fo = *laser frequency*
fs = *bragg frequency shift*
fd = *doppler frequency shift*



Customizable All-weather IR Tag: Smart Dust



- "Dust-like" particles
- IFF Applications: customized to be sensitive at single/multiple wavelengths
- Possible sensitivity to presence/absence of various substances

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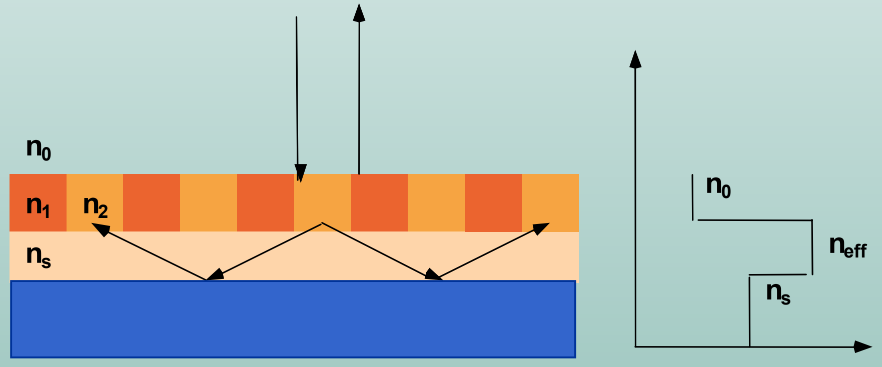
Previous Research in Guided Mode Resonant Filters (GMRFs) Required an Embedded Waveguide Structure

- Coupling orthogonal to surface
- Linear gratings formed by surface relief
- Waveguide/grating couplers
- Resonant narrow band filters



ORNL Initially Worked with Sinusoidal GRMFs due to Ease of Fabrication

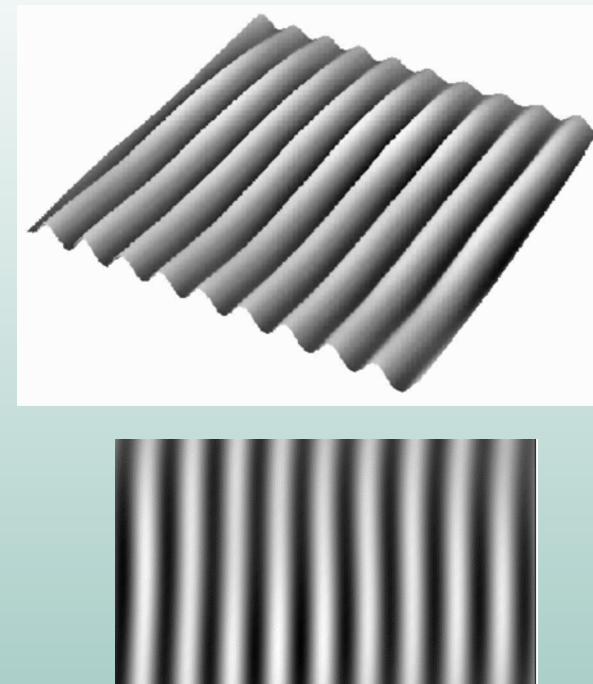
- **Bandwidth (FWHM)**

  $\Delta\phi$ = 0.3°

  --> $\Delta\lambda$ = 0.85nm

- **Performance limitations**
  - grating nonuniformity
    - ghost interference
    - beam nonuniformity
    - mechanical jitter during exposure

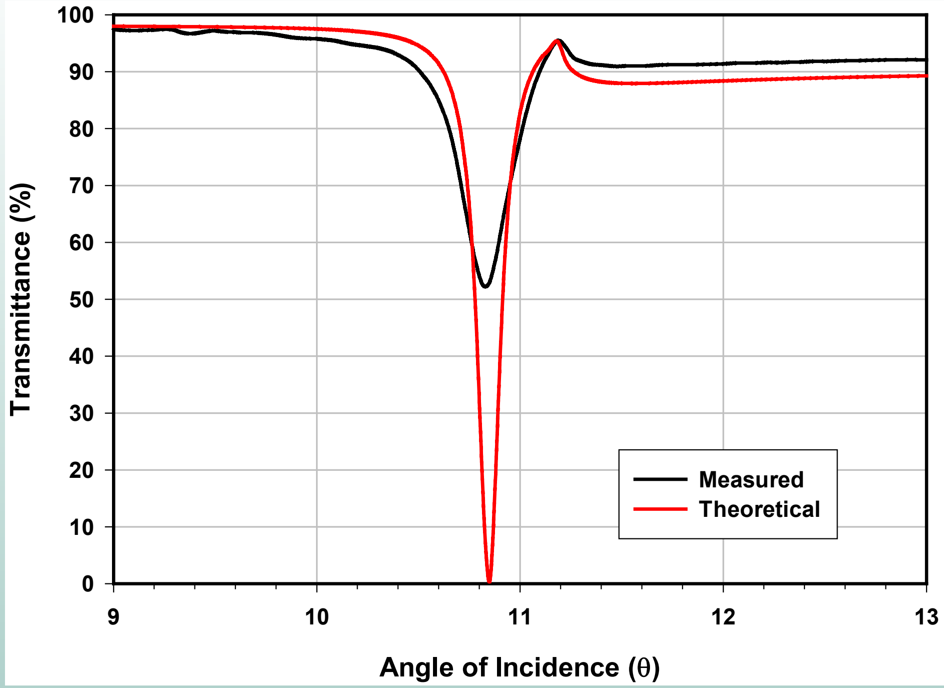
AFM Scan



Sinusoidal GMRF Performance

Grating Specs

TE polarization
$\phi = 0°$
$\lambda = 632.8nm$
$n_o = 1.0$
$n_s = 1.516$
$n_c = 1.64$
$d_c = 145nm$
$d_m = 270nm$
$\Lambda = 370nm$



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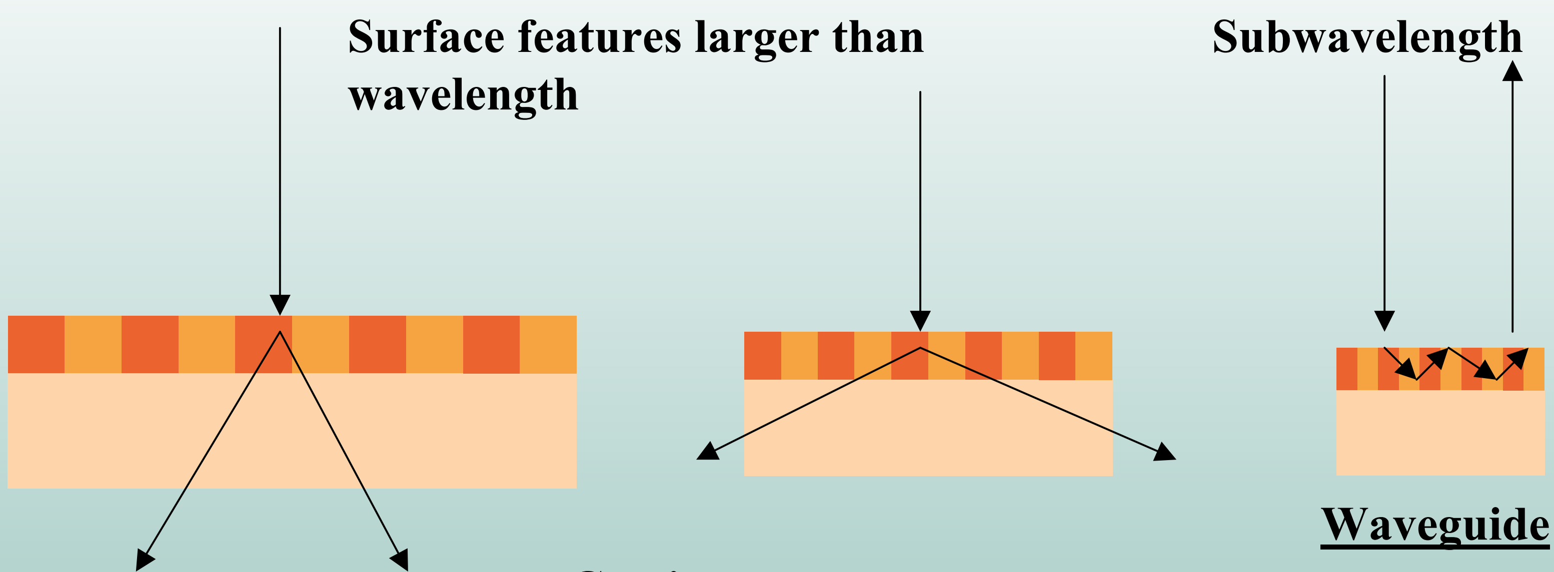
As Surface Features Get Smaller than the Wavelength of Incident Light, Surface Layer Becomes a Waveguide

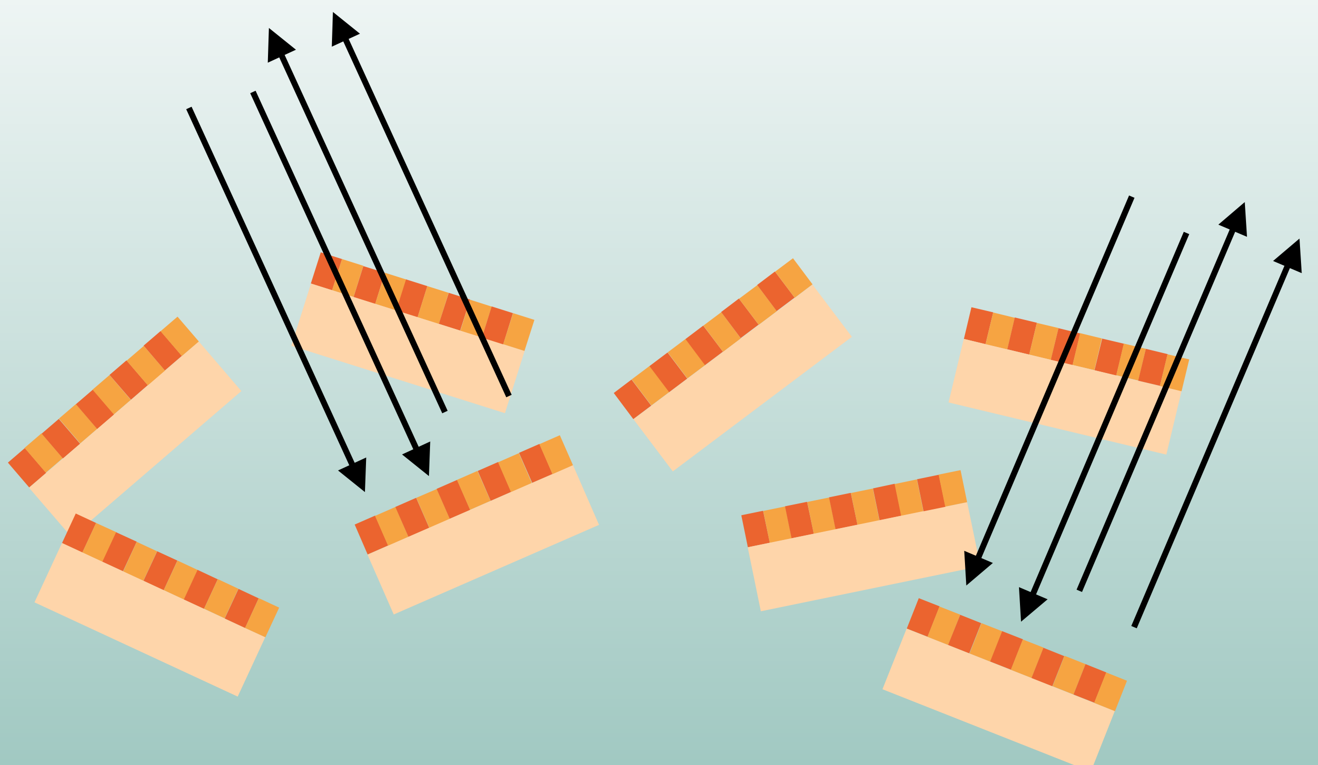


High reflectivity:
Entrance and exit conditions match

Grating

Low reflectivity:
Multiple diffractive orders transmitted

Key to Resonant Dust: Random Orientation Provides Signal Return from Wide Angles



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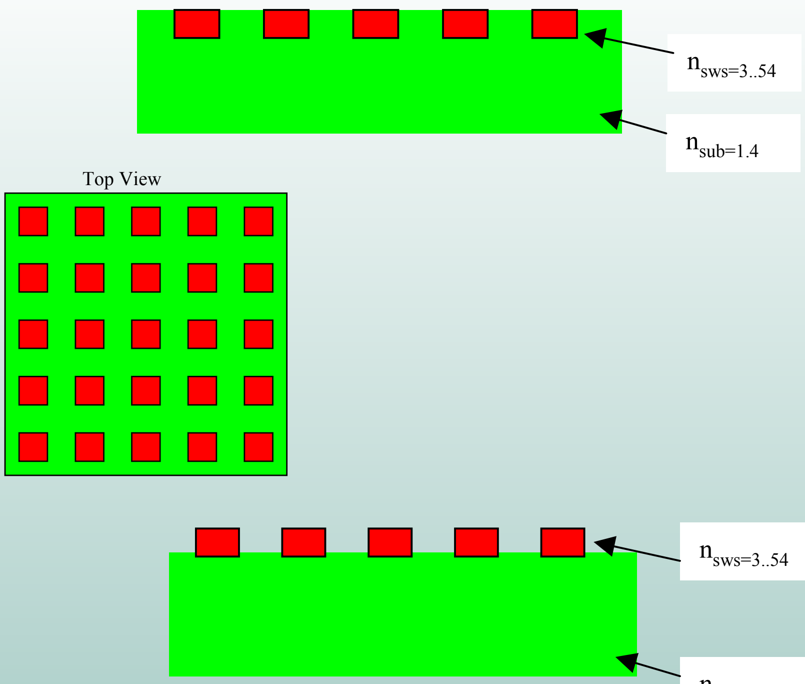
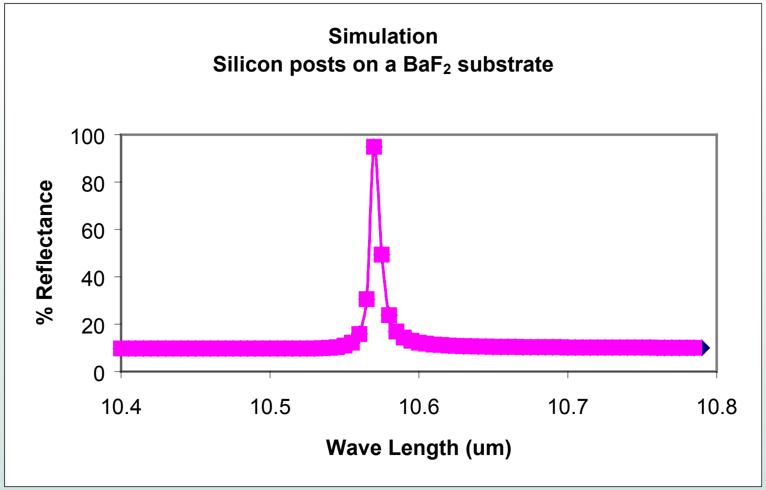
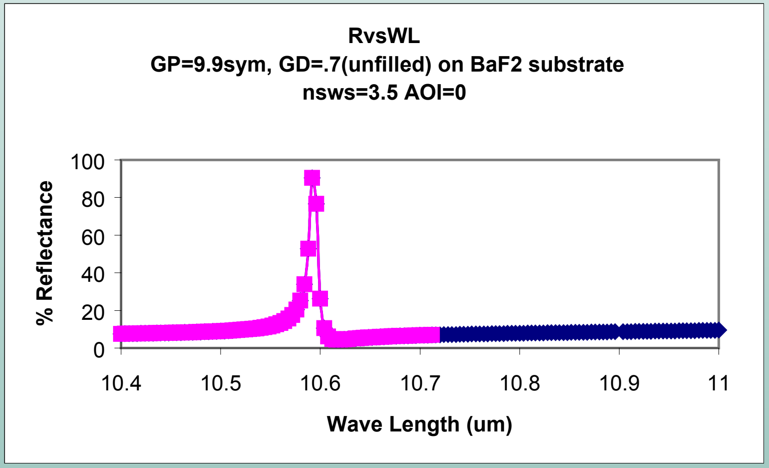
Simulation of Reflectance for 2D SWS Layouts







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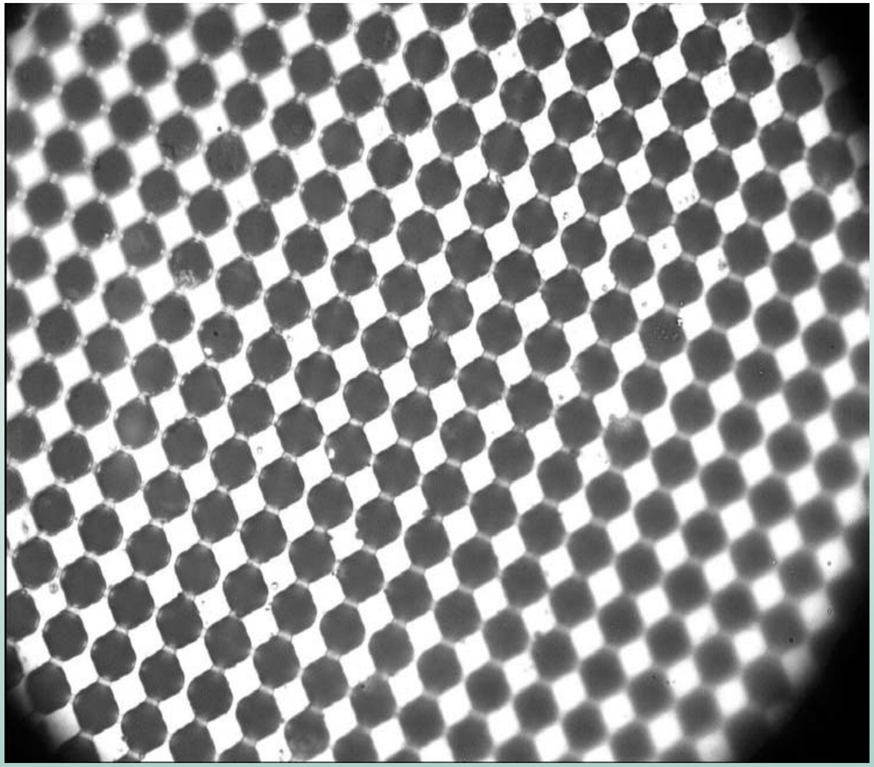
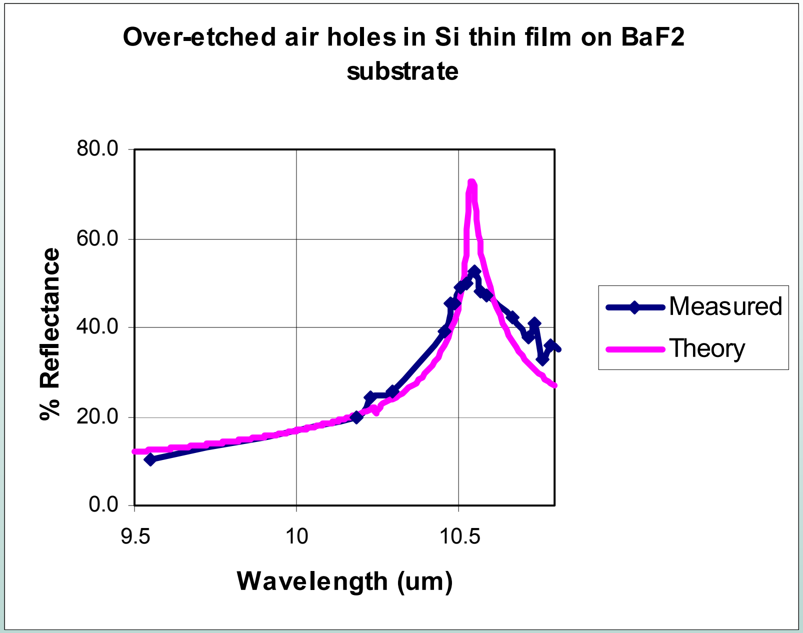
Initial Laboratory Data Supports Resonant Dust Models



Over etched Si on BaF_2 sample



Sample measured reflectance compared with simulated theoretical reflectance

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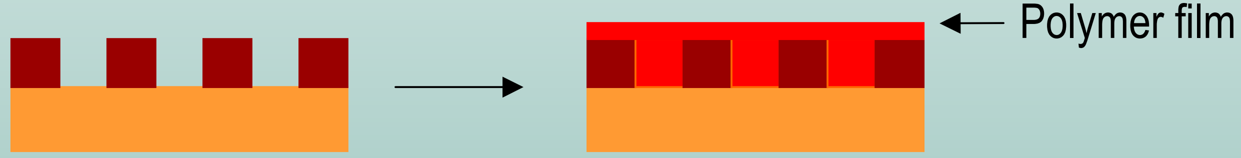
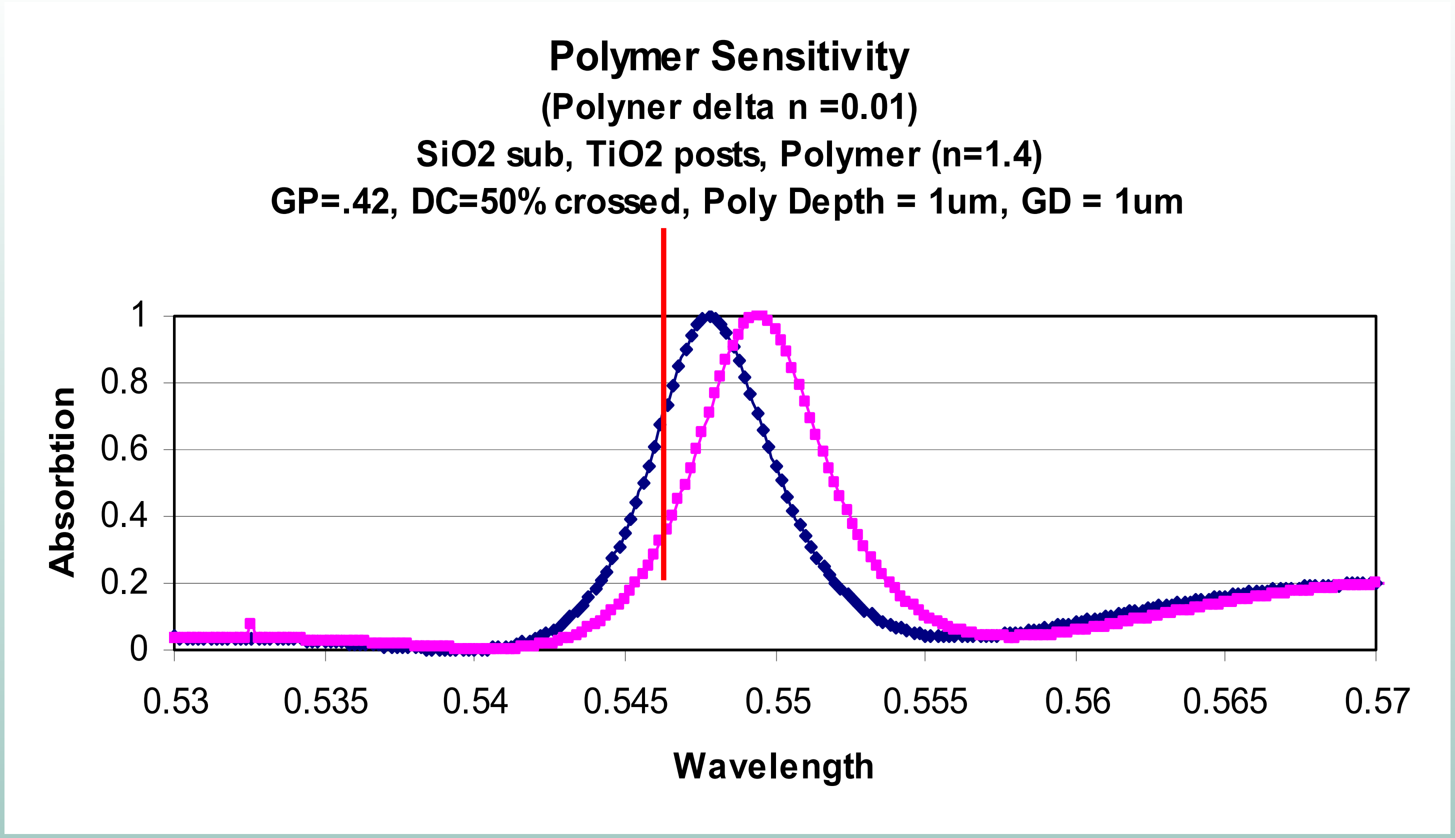
Next Phase: Chemically Selective Resonant Dust

- Polymer film covalently bound on the surface of the resonant dust.
- Adsorption of organic vapors into the polymer film:
  - Changes the polarity of the polymer film (i.e., its dielectric constant) which alters the refractive index of the polymer.
    - For an example see: *Nature* 1996, ***382,*** **697** and *Acc. Chem. Res.* 1998, ***31***, **267**,
  - Swells the polymer film which changes the optical pathlength.

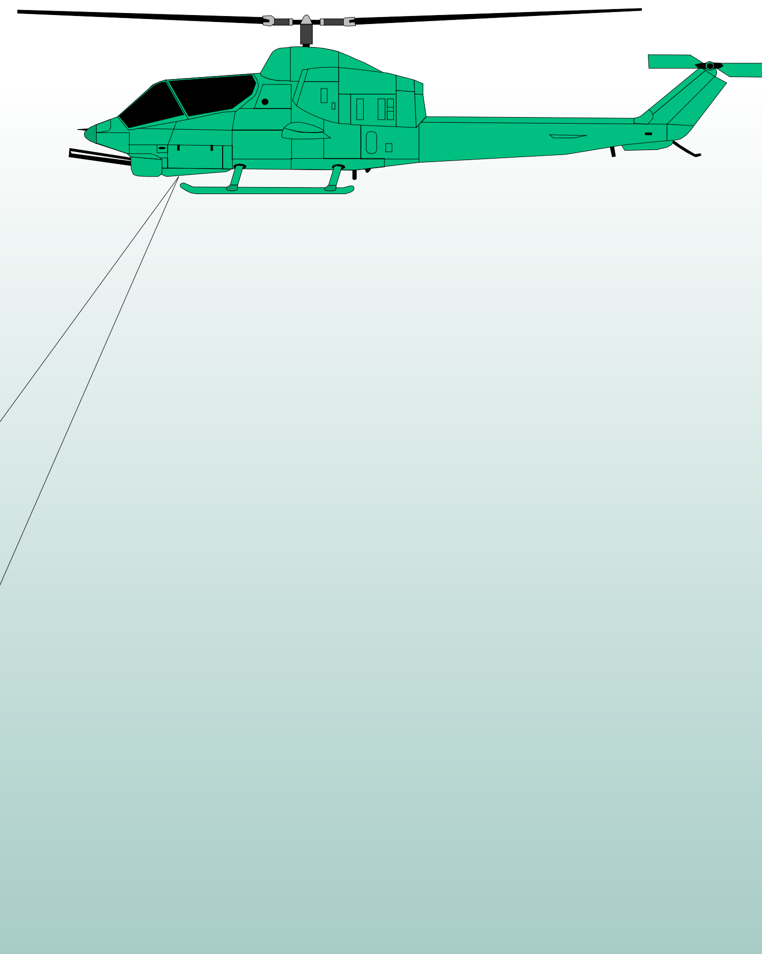


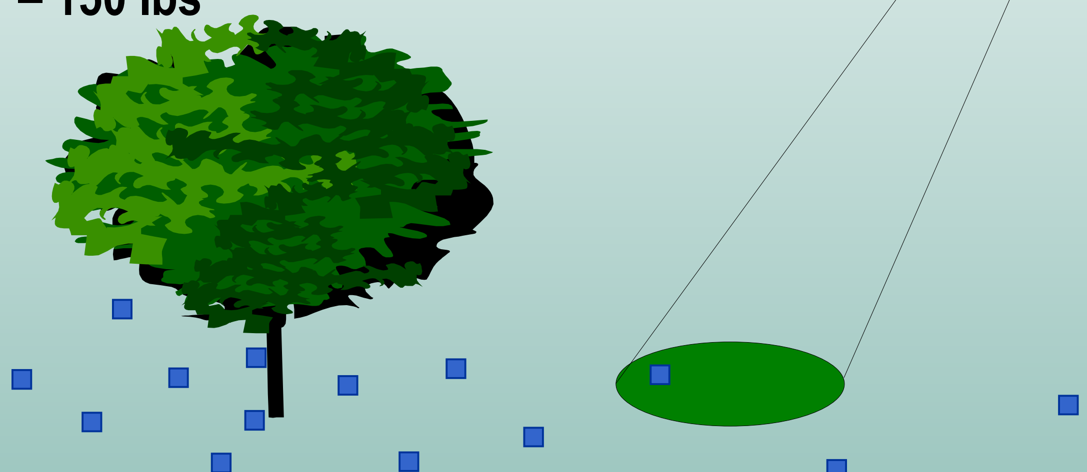
Simulation Showing Change in Reflectivity for Passive Tag Assuming a Polymer Delta n = .01



1 to 5 Km Standoff Optical Read Out of Chem/Bio or IFF Point Sensors

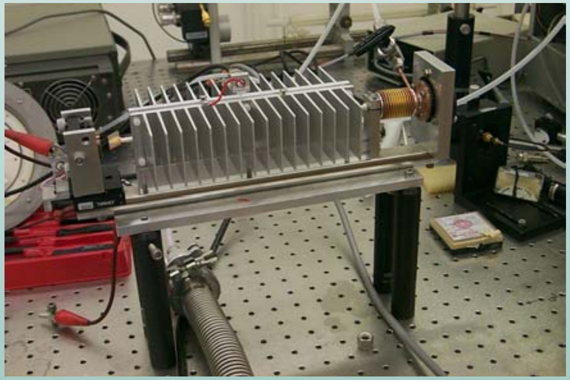
- Distributed chem/bio or IFF point sensors
- Read out based on battery-powered micro cantilevers or resonant dust
- All weather optical receiver (TRL 5)
  - Miniature CO_2 laser and TE-cooled detector
  - 1.0 m^3 footprint
  - 500W input power
  - 150 lbs

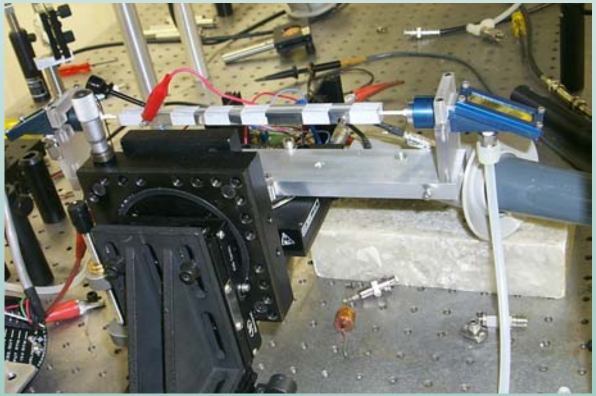




Compact, Low Power Optical Communication 10 Micron Technology Enabling Smaller Lasers, Modulators and Room Temperature Detectors

- Folded cavity and waveguide CO_2 lasers with 0.1 m^2 footprints and >5W output power
- HgCdZnTe and QWIP room temperature/TE cooled detectors
- High bandwidth modulators
- All weather transmission, invisible to night vision gear





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Future Areas for Development in Micro and Nano-structures for Tagging/Tracking: Smarter Tags

- Remote IR readout of microcantilevers
- Anisotropic 2D structures (e.g. polarization sensitivity)
- Customized, multiple wavelength/polarization for ID
- Substance-specific polymer films for detection
- Totally Passive concepts for tags

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