Infrared Antennas & Frequency Selective Surfaces

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CREOL IR Systems Lab


To date, graduated 32 MS students, 22 PhDs.

IR Lab Alumni at:
- NRL, NVL, AF Wright Lab, JPL, Sandia, NASA, GTRI, SRI
- LMCO, Raytheon, Motorola, Harris, Ansoft
- *H N Burns Engineering, Plasmonics Inc.*
- UCF, Penn State, Michigan Tech, Notre Dame…

Research focus:
- Extension of radiofrequency concepts to IR

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Research Approach

We take an experimental approach of design, fabrication, & characterization.

We always compare measured device performance to model predictions.
Electromagnetic Design

Ansoft **HFSS** (finite-element) and **Designer** (method of moments) are our primary design tools for computational electromagnetics.

For the materials used in the devices, we use ellipsometry to measure real & imaginary parts of permittivity from 400 nm to 40 μm.

Using real material data in the EM models improves agreement between design and measured performance.
Measured Metal Conductivities at Infrared
Leica direct-write e-beam lithography system lets us routinely work at the 75- to 100-nm line width for MWIR & LWIR devices.

Hi-vacuum evaporator
- sequential deposition of different layers w/o breaking vacuum
- precise control of oxygen partial pressure
- in-situ ellipsometry for real-time layer thickness monitoring.
Our THz source covers 300 GHz to 7 THz (1 mm to 42 μm), line tunable. Optically-pumped gas laser, the Coherent SIFIR-50 – system has long-wave and short-wave cavities, to avoid over-moding and preserve beam quality. This source enables a variety of research activities: materials characterization, sensor characterization, component development.
THz Materials Characterization

Measurements of fundamental material information in the THz region, e.g.: reflection, transmission, and scattering; also refractive index and material dispersion.
Selected IR Lab Research Areas

• IR Antenna-Coupled Sensors
• IR Frequency-Selective Surfaces
• IR Meanderlines
• IR Reflectarrays
• IR Vector Near-Field Mapping
IR Antennas

At any wavelength, an antenna allows a sub-wavelength-sized sensor to respond to incident EM radiation.

Incident radiation induces IR-frequency current waves to flow in the arms of the antenna, and puts an IR-frequency sinusoidal voltage across the sensor element.

Most of our devices use bolometers (temperature dependent resistors) or tunnel diodes (fast rectifiers) as the sensing element.
Antenna-Coupled IR Tunnel Diodes

Metal-oxide-metal (MOM) layered structure, acts as a rectifier. Contact area must be small for IR-frequency rectification.

75 nm by 75 nm is typical – with a 2-nm oxide layer, this area gives 25 attofarad capacitance.
IR Antennas – Resonant Wavelength

Spectral response determined by antenna dimensions rather than by sensor-material characteristics - visible to IR to mmW demonstrated.

Overall dimensions of the antenna determine the primary resonance.

Typically a half-wave resonance for a linear antenna like a dipole or bowtie; or circumference equals full-wave for a spiral or logperiodic.
IR Antennas – Bandwidth

Antenna design form determines the spectral bandwidth around the main resonance.

Narrowest response: microstrip patch
Narrow response: dipole
Wide response: bowtie
Widest response: logperiodic, spiral.
IR Transmission Lines

IR coplanar-strip transmission lines have been characterized for impedance and attenuation – fixed antenna structure and load impedance – vary transmission-line length and fit measured parameters to model.
IR Phased-Array Antennas

IR phased-array antennas are able to synthesize a narrow far-field angular beam by coherent combination of signals from more than one antenna.

Distinguish phase-incoherent vs phase-coherent interconnection: below is a series interconnection of bolometers, each with its own IR antenna – gives extended spatial response. Not a phased array since signals combine without phase information.
IR Phased-Array Antennas

Interconnection of two dipole antennas with co-planar waveguide preserves relative phase of current waves. Applications in tailoring the angular response of the sensor, and in measurement of coherence.
IR Phased-Array Antennas

Offsetting the diode from equal-phase position in the center produces angular-response with an off-axis maximum.
IR Phased-Array Antennas

Sensor of a two-element symmetric phased-array antenna measures correlation of the electric field at the locations of the two antennas.

If antenna currents are in-phase, the diode response will be a maximum. If they are $180^\circ$ out of phase then currents will cancel at the diode and the response will be zero.

A series of antenna spacings allows coherence measurement.
IR Frequency-Selective Surfaces

Resonant wavelength & spectral bandwidth of the FSS are controlled by geometry of the subwavelength-periodic metallic structures on dielectric substrates; essentially an RLC circuit, resonant in the IR.

Spectral control of reflection, transmission, emissivity.

Various unit cells can be used – design models give accurate results if IR-material properties are included.
IR FSS as Reflection & Transmission Filters

Array of conducting elements passes radiation except at resonance, leading to band-stop filter.

Array of slots blocks radiation except at resonance, leading to band-pass filter.
IR FSS as Selective Emitters

With inclusion of a groundplane and a quarter-wave standoff layer, the IR FSS can be configured to produce a spectrally selective absorber.

Useful feature of the lossy IR FSS is the ability to control the **spectral absorption**, and hence by Kirchhoff’s Law – the spectral emissivity (*infrared signature*).
IR FSS as Selective Emitters

IR spectroradiometer: 3 to 14\(\mu m\)

Data were taken at \(T=200^\circ C\)

IR FSS can enhance or reduce emissivity in selected bands – reduce contrast with respect to background, or increase it. Excellent emissivity range: 10 to 95%.

One FSS layer has a single RLC resonance with given spectral location and width – can add more spectral features with additional layers or more complex unit cell.
For extended-area IR FSS coverage, metamaterial paint is an option.

- Under a one-year program from Sandia National Labs, we developed fabrication processes for releasable flakes of IR FSS materials.
- Teamed with Plasmonics, Inc. (CREOL incubator).
- Flakes are symmetric about centerline so that either side can face up.
- Near-symmetric rotationally to avoid polarization or orientation dependence.
- The flakes are flat with no curling, and naturally tend to settle onto a surface flat rather than end-on.
Large-Area IR FSS

Long-range order in the FSS is not required. A region about 10 by 10 unit cells gives good agreement between full-array behavior and a collection of flakes, accounting for fill factor of % coverage of flakes within the field of view of the measuring instrument.

Similar spectral trends seen in HFSS model and in measured data.

We have experimentally demonstrated the concept of a releasable metamaterial with well-defined spectral signature.
Large-Area IR FSS

For extended-area IR FSS, another option is imprint lithography.

Below is our etched-Si master used for imprinting process, an intermediate step of an imprinted FSS design in a polymer layer, and a final replicated FSS sheet.
**IR Reflectarray**

Sub-\(\lambda\) periodic surface over a groundplane – its phase shift on reflection depends on the unit-cell geometry.

Unit-cell dimensions within the sub-wavelength unit cell vary across the array, producing a spatially varying phase.

We demonstrate a square-patch design, vary patch dimensions. Applications include low-cost lithographic IR optics, conformal optics, new degrees of freedom for aberration correction.

![Graph showing phase shift vs. patch size](image1)

![Image of reflectarray design](image2)

- 3.25 µm
- 3.15 µm
- 3.00 µm
IR Reflectarray Aberrations

A focusing reflectarray is configured by a Fresnel-zone arrangement, where successive zones have a distinct phase shift on reflection.

These surfaces have unique aberration characteristics compared to classical optical components such as lenses or mirrors. Investigating the monochromatic and chromatic aberrations, we see effects from the geometry of the zonal arrangement as well as from the EM response of the unit cells.
IR Reflectarray Aberrations

Show computed magnitude & phase of reflectance as a function of angle, polarization state, and wavelength.

Unit-cell chromatic dependence may be used to compensate the strong chromatic behavior of the Fresnel-zone arrangement.
Meanderline waveplates have been demonstrated on both flexible and rigid substrates, in practical sizes for implementation in IR systems.

Tag microstructure consists of a meanderline arrangement of metallic wires – phase delay between TE & TM waves.
IR Meanderline

IR meanderlines create circular polarizing (CP) elements with wide spectral & angular bandwidth at any given frequency in NIR, MWIR, LWIR, or THz.

Advantages compared to present technology:
* Very thin – easy to integrate into an optical train
* Broadband in wavelength
* Broadband in angle
* Can design for any wavelength of interest.
IR Meanderline

Nearly achromatic performance demonstrated over whole 3-5 or 8-12 μm bands.

Stable performance as a function of angle to ± 40 degrees.

Best transmittance into circular polarization (with linear polarized input) presently about 75%.
MWIR CP Tag Demo

CP tag demo is 4 quadrants, with 2 RCP and 2 LCP segments. To see CP tag, need a CP filter, which has been demonstrated as integrated component on COTS MWIR camera.

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Sam Wadsworth, completing PhD in Optics, July 2011.
Today’s Lab Tour: Room 130.
IR Vector Near-Field Mapping

10 μm radiation of known polarization illuminates the antenna and excites fields on the metallic surface. AFM tip is brought into the reactive near field of the structure – scanned in 3 dimensions with nanometer spatial resolution. Backscattered radiation is detected interferometrically, which maps the electric-field magnitude and phase.
IR Vector Near-Field Mapping

Data can be used to assess impedance at IR frequencies at any location on antenna, transmission line or sensor. Applications in impedance matching, investigation of loss mechanisms, corroboration of computational models for both IR antennas & FSS structures.

Dr. Ed Kinzel
Today’s Lab Tour: Room 125.
Future Directions

Fabrication and commercialization of antenna-coupled IR sensors and IR FSSs will be continued by Plasmonics, Inc., a small business founded by two UCF grads, Dr. David Shelton, Dr. James Ginn, and myself. www.photonics-inc.com.

Located in the CREOL Photonics Incubator (Room A218).
Future Directions

This fall I begin a new phase in my career, as Chairman of the Dept. of Physics & Optical Science at Univ. of North Carolina at Charlotte. My research there will continue with design and measurement of IR devices & surfaces, along with new work in BRDF characterization of optical-fabrication processes, in collaboration with UNCC’s Center for Precision Metrology.