Antennas are common in the microwave and millimeter-wave portions of the spectrum. At any wavelength, an antenna allows a sub-wavelength-sized sensor to present an appreciable capture cross-section to incident electromagnetic radiation. Classical IR detectors use photon absorption in the photosensitive material to perform both the radiation-collection and the radiation-sensing functions. This approach can limit performance, however, prompting engineers to seek alternatives.

Antenna-coupling techniques at IR wavelengths provide a method for separating radiation collection from radiation sensing, providing a flexibility that can yield performance advantages over classical IR detectors. Detectors with antennas can offer rapid response time, for example, as well as on-chip polarization tuning and on-chip wavelength tuning. Our group at University of Central Florida (UCF; Orlando, FL) is currently developing these types of designs. Next-generation IR focal plane arrays (FPAs) of antenna-coupled sensors will lead directly to spectrally resolved imagers and imaging polarimeters with no moving parts, which will be useful in a range of applications that require dynamic target information.

Consider a niobium bolometer with a dipole antenna. The incident radiation excites current waves at IR frequencies in the gold arms of the antenna. These currents are dissipated in the bolometer, just as in conventional bolometric sensors, Joule heating raises the temperature of the structure, causing a resistance change that is sensed externally. The antenna-coupled sensor differs from conventional designs in that the antenna, rather than the sensor, collects the radiation. This approach allows the sensor itself to be very small—in this case around 0.5 × 1.0 µm. The size of the sensor improves the time response because there is much less thermal mass than in a classical IR bolometer.

Antenna-coupled bolometers commonly achieve time responses of 100 ns, with shorter times possible depending upon the thermal isolation of the sensor element. This is an advantage in tracking scenarios that demand fast response times that cannot be met by existing uncooled IR FPAs, which typically run at 30 frames/s.

Other sensors can be placed at the focus of the antenna. We are also investigating tunnel diodes, which rectify the IR-frequency current waves in the antenna arms. The response time of IR antenna-coupled tunnel diodes can be in the picosecond range. An additional advantage of uncooled devices such as microbolometers is that their spectral response extends into the very-longwave IR region beyond 12 µm. The band gap-based photon sensors commonly used at these wavelengths require excessively cold temperatures to reduce thermally generated dark current.

The main advantage of antenna-coupled IR sensors is the ability to modify the propagation of current waves on the antenna. For remote-sensing applications, the goal is to pro-
duce pixel-integrated imaging polarimeters and spectral imagers directly on the IR FPA without the need for external optical filter elements or moving parts. The antenna-coupled design provides a completely electronic mechanism for polarization and wavelength tuning. Consider a spiral antenna coupled to a tunnel-diode sensor. The capacitance of the diode is a function of voltage. Tuning the capacitance of the load impedance changes the standing-wave current distribution on the antenna arms and hence the polarization state of the radiation detected. One can adjust the polarization signature of the received IR signal from horizontal to vertical, for example, by applying a control voltage of around 100 mV. Similarly, wavelength tuning can be implemented by capacitive modulation of the electrical length of a narrowband-patch IR antenna (see figure 1).

**fabrication and test**

IR antennas are typically fabricated as planar structures on silicon substrates using direct-write electron-beam lithography, which in turn usually uses a bilayer resist. The required on-chip resolution is on the order of 0.1 \( \mu \)m. The antennas themselves can be made from any high-conductivity metal, for example, aluminum, gold, or nickel. Dielectric spacer layers, such as those arising in patch antennas, are often made from silicon oxide. Deposition of the metals and dielectrics can be accomplished in a variety of ways, including direct-current and radio-frequency sputtering, thermal evaporation, and electron-beam evaporation. These methods allow engineers to fabricate many different types of planar IR antennas, including dipoles, spirals, and patches.

Antennas are usually tested for their angular response using collimated radiation to determine their far-field radiation pattern. For IR FPA applications, however, we are more interested in measuring the spatial response of the antenna-coupled sensor. The collection area is necessary to calculate received power, noise-equivalent power, and responsivity. That information lets us compare the signal-to-noise ratios and radiometric quality of devices and provides insight into current-wave modes for a given antenna device. To determine this near-field response, we make a 2-D scan of a tightly focused, polarized beam across the antenna’s receiving area. Deconvolution of the known beam profile lets us determine the spatial response (see figure 2).

We find that individual antenna-coupled sensors have a collection area as small as wavelength squared—nearly a point receiver. Smaller pixels yield higher resolution for a given chip size, a property that can potentially result in oversampling the image. In high-resolution tracking systems, for example, such high sampling densities may be advantageous, but most IR-imaging systems benefit from larger pixels—are receivers rather than point receivers. For these cases, antenna-coupled IR sensors can be interconnected to form pixels with uniform response across a square area of around 20 to 50 \( \mu \)m on a side. These antenna-array pixels can be fabricated at successive locations on a readout multiplexer chip to yield an IR FPA.

Antenna-coupled IR FPAs should find application in thermal-imaging systems requiring a fast uncooled response, on-chip wavelength and polarization-tuning capability, high spatial resolution, or extra-long wavelength response. IR antennas will make it easier to put more imaging capability into a smaller, lighter-weight package, which is important for a range of remote-sensing applications, including satellite and handheld systems.

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