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Microelectronics and Microsystems
Photonics

Thermal Microphotonic Detection and Imaging

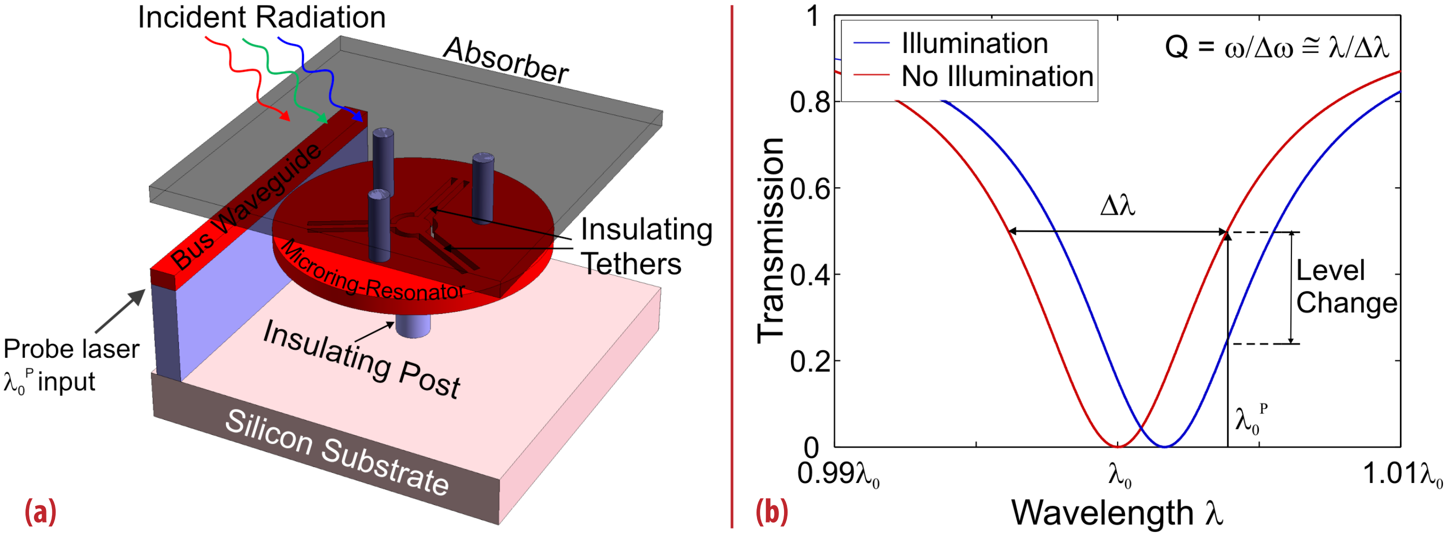

Figure 1: Thermal detection using optical resonators. (a) Schematic of a thermal microphotonic detector, consisting of a thermally isolated resonator thermally coupled to an absorbing element and evanescently coupled to a bus waveguide. (b) Readout consists of an interrogating laser sitting at the 3dB point of the resonance. Upon illumination, the temperature of the microresonator increases, shifting the resonant wavelength via the thermo-optic effect and a level change is sensed.

> *Optical resonators offer potential for significant improvements in thermal imaging*

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Most modern optical imagers, such as focal plane arrays (FPAs), are constructed of arrays of photon detectors. The detectors directly generate electron-hole pairs from the incident radiation and provide excellent noise performance when the photon energy is much larger than the thermal energy k_BT. However, for wavelengths longer than a few microns, photon detectors have to be cooled, often to cryogenic temperatures, in order to minimize thermally-induced transitions. Alternatively, thermal FPAs can be formed from uncooled detectors, where the incident radiation generates thermal energy and a corresponding temperature shift. This shift is then sensed through a change in some physical characteristic (e.g., mechanical, electrical, or optical) of the detector element.

Fundamentally, thermal detectors are limited by thermal phonon fluctuations due to energy exchange with their surroundings. However, the best thermal detectors (i.e. microbolometers), do not reach the thermal phonon fluctuation limit since resistive elements in microbolometers suffer from Johnson noise, $1/f$ noise, and poor thermal isolation.

At Sandia, we are developing uncooled thermal detectors based on microphotonic resonators that offer better noise performance, smaller pixel size (5μm), and faster response times than existing thermal detectors. Thermal microphotonic detection involves combining high-quality-factor-(Q-) micron-scale resonators with extreme thermal isolation to ensure low-noise thermal detection. As shown in Fig. 1a, it consists of a bus waveguide, a thermally-isolated microresonator, and an absorbing element in thermal contact with the microresonator. The absorber converts incident optical power to thermal power, causing a rise in temperature in both the absorber and the resonator. This temperature rise shifts the resonance through the thermo-optic effect, as depicted in Fig. 1b. The shift can be

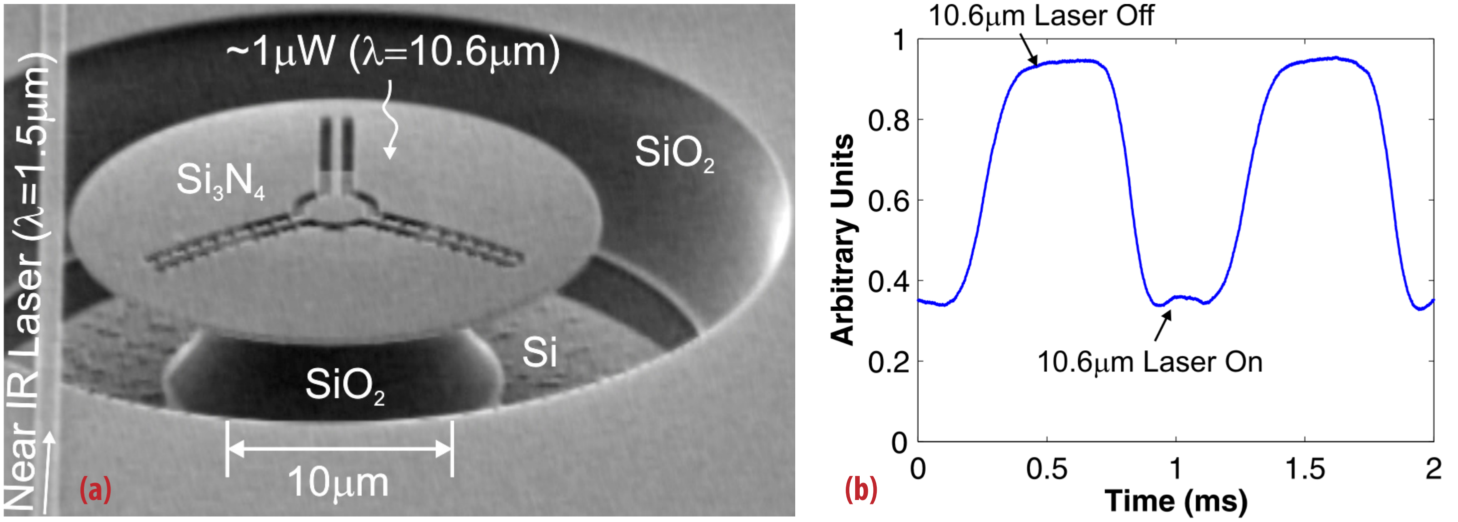

Figure 2: Prototype microphotonic thermal detectors. (a) Scanning electron micrograph of a silicon-nitride-based detector. (b) Resonator response to absorption of chopped 1μW 10.6μm CO_2 laser. The resulting temperature change induces a change in the transmission of the near-infrared (λ = 1.5μm) laser line interrogating the resonator as described in Fig. 1b.

detected by a laser line operating at one of the 3dB points of the resonance. The very high Q, along with the high degree of thermal isolation that can be achieved by dielectric supports, enables thermal microphotonic detectors to achieve scale factors three-to-four orders of magnitude greater than that achieved with microbolometers. In addition, microphotonic detectors do not suffer from Johnson noise in the sensing element, do not have significant $1/f$ noise components, and are not perturbed by the interrogating signal. All of these traits point to the potential to measure thermal fluctuations two-orders of magnitude below present day microbolometer performance.

Prototype microphotonic detectors have been designed and fabricated at Sandia. A scanning electron micrograph of a detector made of silicon nitride and supported by an oxide post and silicon nitride tethers is presented in Fig. 2a. (Note: The resonator itself is the absorbing element in this prototype). The response to incident thermal radiation (Fig 2b) was obtained by interrogating the 3dB point of the resonance with a near-infrared laser (λ = 1.5μm) and directly illuminating the absorbing microphotonic resonator with 1μW from a 10.6μm carbon dioxide laser.

Scaling up from a single prototype sensor to a working thermal microphotonic focal plane array (TM-FPA, Fig. 3) will certainly require significant effort. Principal among the challenges is to adopt a scalable and reliable readout approach, such as a wavelength division multiplexed (WDM) readout, whereby an interrogating laser's frequency is scanned to address columns of resonators with different resonant frequencies. If successful, thermal microphotonic detectors and imagers have the potential to transform uncooled thermal imaging technology, enabling higher sensitivity, higher resolution, and faster response times.

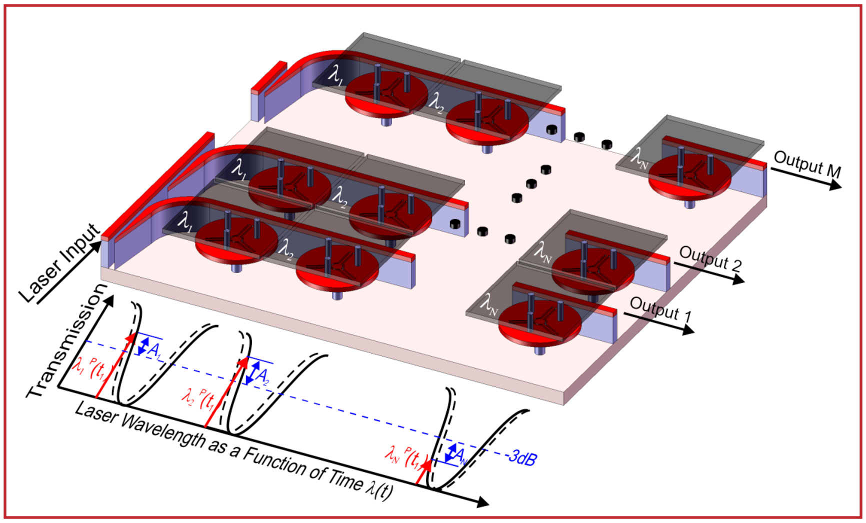

Figure 3: Concept for a TM-FPA, using a WDM-based readout to interrogate columns of sensors. The resonances can be interrogated by simply stepping the laser to a 3dB point of the initial center wavelength of each column and reading out the amplitudes of transmission.

Reference:

M. R. Watts, M. J. Shaw, G. N. Nielson, "Optical resonators: Microphotonic thermal imaging," Nature Photonics, **1**, 632 - 634 (2007)

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