Long Wavelength Infrared Detection by Combining Nano-Thermoelectrics and Sub-Wavelength Absorbers

Aapo Varpula, Anton Murros, Kuura Sovanto, Jonna Tiira, Kirsi Tappura, and Mika Prunnila*

VTT Technical Research Centre of Finland Ltd, Tietotie 3, FI-02150 Espoo, Finland
*corresponding author, E-mail: mika.prunnila@vtt.fi

Abstract

Detection of infrared (IR) radiation is required in numerous applications from spectroscopic gas sensing to thermal imaging. Obtaining high speed and sensitivity, low-power operation, and cost-effectiveness with a single technology remains to be a challenge in the field of IR sensing. By combining nano-thermoelectric heat-to-voltage transduction and sub-wavelength absorbers, we demonstrate uncooled IR bolometer technology that provides fast and high sensitivity response to long-wavelength IR (LWIR) around 8 - 12 μm and is material-compatible with large-scale CMOS fabrication.

The state-of-the-art optical detectors are either bolometers or quantum photodetectors. In the infrared (IR) range, the state-of-the-art bolometers convert the IR signal into an electric signal using either temperature-dependent resistors or thermoelectrics. Quantum IR photodetectors have high performance, but they require cooling, and exotic materials at longer wavelengths. Compared to quantum IR photodetectors, IR bolometers offer lower cost without need for cooling, but they are typically much slower and less sensitive.

Nano-thermoelectrics has been mainly driven by applications in thermal energy harvesting with very little attention to detectors until recently when it was postulated [1,2] and demonstrated [3] that nano-thermoelectrics can provide an attractive low noise transduction method for bolometers. When nano-thermoelectric beams are combined with nanomembrane IR absorbers with inherently low thermal mass, they can be utilized as fast and sensitive infrared detectors [3] (see also Fig. 1). The nano-thermoelectric transducer-support approach benefits from enhanced phonon scattering in the beams, which enhances the sensitivity. We have demonstrated different size nano-thermoelectric bolometric photodetector pixels with LWIR responsitivities, specific detectivities, and time constants in the ranges 179 V/W–2930 V/W, 1.5×10^7 cm Hz$^{1/2}$/W–3.1×10^8 cm Hz$^{1/2}$/W, and 66 μs–3600 μs, respectively. We have also benchmarked the technology against different LWIR detector solutions and showed how nano-thermoelectric detector technology can reach the fundamental sensitivity limits posed by phonon and photon thermal fluctuation noise [3].

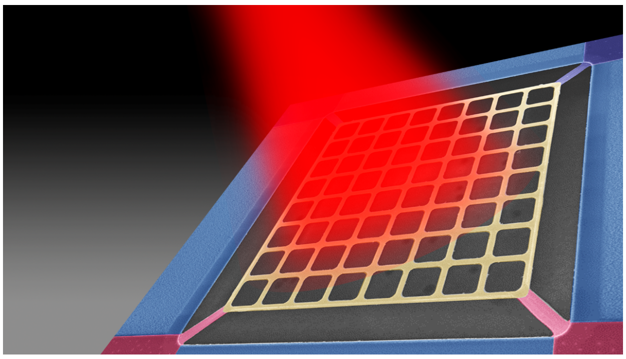

Figure 1: Nano-thermoelectric LWIR bolometer [3].

[1] A. Varpula et al., Appl. Phys. Lett. 110, 262101 (2017).

[2] A. Varpula et al., Proceedings 2 (13), 894 (2018).

[3] A. Varpula, K. Tappura, J. Tiira, K. Grigoras, O.-P. Kilpi, K. Sovanto, J. Ahopelto, and M. Prunnila, "Nano-thermoelectric infrared bolometers", APL Photonics 6, 036111 (2021).