Broadband absolute radiometers for far infrared sensing

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Currently the Earth's outgoing longwave radiation (OLR, 3 µm – 100 µm) is being imaged with scanning, single-element radiometers on the NASA CERES satellite instrument. Despite the need for increased spatial resolution, scanning radiometers are slated for future missions due to lack of a better alternative. For example, microbolometer staring arrays, which are technologically mature, do not possess the accuracy or broadband absorption required by climate scientists for OLR imaging. I will discuss our efforts to develop a new type of uncooled microbolometer consisting of electrical substitution radiometers (ESRs) capable of sensing out to 100 µm for smallsat remote sensing.

INTRODUCTION

Absolute radiometry using an electrical substitution radiometer (ESR) has not fundamentally changed since its conception by Kurlbaum (1892) and Ångstrom (1893) [1]. To this day, incident optical power is determined by measuring the ohmic heating required to achieve an equivalent signal in a transducer (e.g. thermistor or thermopile) when non-illuminated. Thus, the measurement does not depend upon a calibrated transducer or material properties of the thermal absorber (i.e. knowledge of specific heat or thermal conductance is not required). A significant improvement to the concept of the ESR has been the development of the active cavity radiometer (ACR) [2], which has improved accuracy, broadband absorption and total absorption. However, ACRs typically possess time constants on the order of tens of seconds and are cm-scale; thus, making them incompatible for imaging.

In the 1970s, Honeywell developed the microbolometer for low size, weight, and power (SWaP) imaging of thermal radiation from 7 µm – 15 µm. While microbolometers are fast (video frame rates) and uncooled making them ideal for CubeSats, OLR imaging is problematic since their absorption is narrowband and calibration of each pixel's thermistor is required for radiometric grade imaging. Recently, several research groups have adapted microbolometer arrays in a number of ways for satellite based OLR sensing. Deposition of gold black on the pixels to increase absorption out to 100 µm [3,4], as well as ESR operation of a silicon micromachined pixel have both been demonstrated [5].

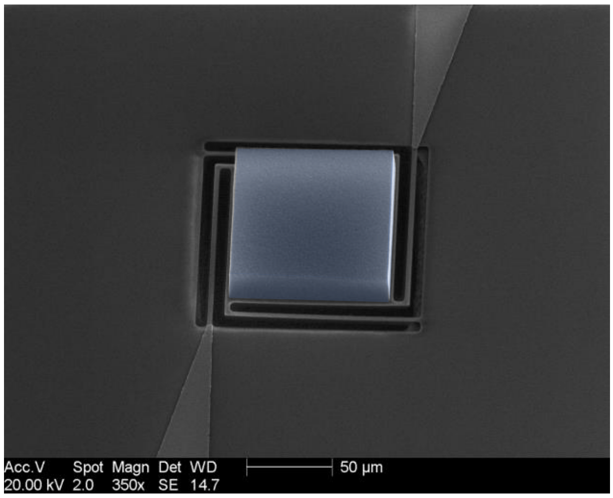

Figure 1. Scanning electron microscope image of a prototype single-element ESR. The element is thermally decoupled from the substrate by four silicon nitride legs. The broadband VACNT absorber (false colored blue) is approximately 22 µm tall and sits above a thin film VO_x thermistor.

In collaboration with LASP, we have demonstrated cm-scale ESRs using vertically aligned carbon nanotubes (VACNTs) as broadband absorbers for CubeSat applications. The Compact Solar Irradiance Measurement (CSIM) [6], currently in space, uses a NIST/LASP developed ESR to track degradation of the photodiodes. The ESR is a silicon micromachined, cm-scale device with hand placed thermistors. We aim to further advance this technology to develop an active microradiometer (AMR) - an imaging array combining the benefits of both microbolometers and ACRs.

DISCUSSION

Figure 1 is an SEM image of a silicon micromachined prototype pixel/element to demonstrate the feasibility of integrating VACNTs with microbolometers. VACNTs were chosen specifically for their

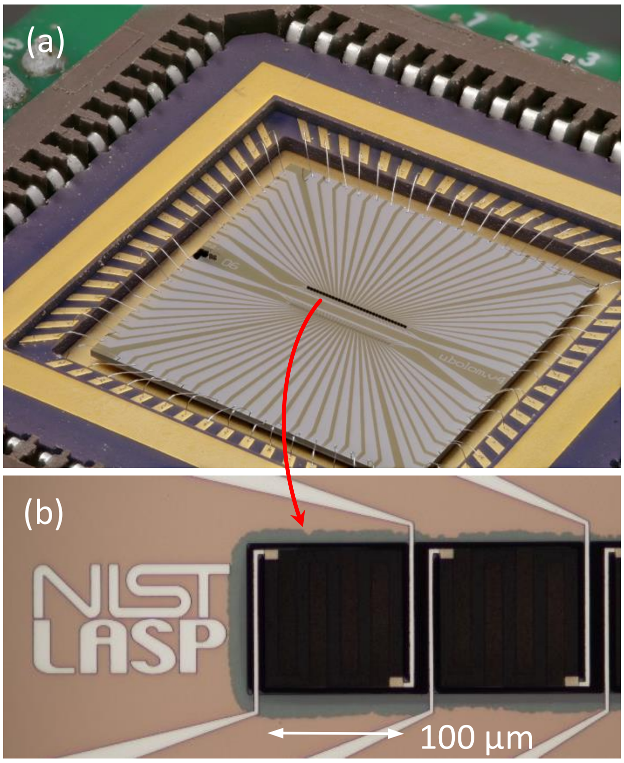

Figure 2. (a) Linear array of 32 ESR elements wire bonded and packaged in a leadless chip carrier. (b) Microscope image of the first two pixels of the linear array. Elements are similar to the prototype in Fig. 1., but with two silicon nitride support legs.

broadband absorptance (> 99%) out to 100 µm. Pixels were fabricated on 2 µm thick silicon nitride membranes with further thermal isolation provided by etching four legs (5 µm x 126 µm) into the membrane. Thin film vanadium oxide (VO_x) thermistors were lithographically defined and sputtered on the pixel. Fe/AlO_x catalyst was co-located over the VO_x thermistor and VACNTs were grown at 800 °C in a mixture of Ar/H_2/C_2H_4 for 20 min. VO_x thermistors display a temperature coefficient of resistance (TCR) of approximately -1 %/K after VACNT growth [6]. In addition, we have demonstrated ACR-like operation of the pixel by using the thermistor as a heater as well. Actively controlling the ohmic heat dissipated in the pixel, we can reduce the natural time constant from 50 ms to 10 ms.

Figure 2 is an optical image of a full 32-element linear imaging array. The top line of pixels (look black due to the VACNTs) are the active sensing elements, while the bottom row of 32 pixels (without VACNTs) are compensating elements used for common mode rejection of substrate temperature fluctuations if placed in a bridge with the sensing pixels.

Future work entails increasing the TCR of the thermistor while minimizing the 1/*f* noise, developing the electronics to support active control/readout of a 32-element array, and radiometric bench testing to evaluate ultimate performance.

SUMMARY

Active microradiometers are a nascent technology potentially meeting the requirements of imaging Earth's OLR. Simple modifications of operating the individual pixels in similar fashion to active cavity radiometers and integrating VACNTs as broadband absorbers will allow for absolute radiometric imaging into the far infrared.

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