HEB FPA Imaging Technology for Security and Biomedical Applications*

E. Gerecht[1], D. Gu[1], S. Yngvesson[2], F. Rodriguez-Morales[2], R. Zannoni[2], J. Nicholson[2],

[1]National Institute of Standards and Technology, Boulder, CO 80305
e-mail: gerecht@boulder.nist.gov
[2]Department of Electrical and Computer Engineering, University of Massachusetts at Amherst, MA 01003

Abstract

We have demonstrated a low-noise heterodyne three-element focal plane array (FPA) at 1.6 THz consisting of NbN Hot Electron Bolometric (HEB) detectors, intimately integrated with monolithic microwave integrated circuit (MMIC) IF amplifiers in a single block. HEB technology is becoming the basis for advanced terahertz imaging and spectroscopic technologies for the study of biological and chemical agents over the entire terahertz spectrum. The use of FPAs is crucial for maximizing the detection speed in these applications.

Introduction

Hot electron bolometric (HEB) mixer receivers for terahertz frequencies have been under development during the past ten years. The *TREND* receiver, based on HEB technology, was deployed at the South Pole three years ago [1]. In order to achieve the required sensitivity for astronomical, remote-sensing, homeland security, and biomedical applications, we need receivers operating at sensitivities near the quantum noise limit, and focal plane arrays (FPAs) with multiple mixer elements. HEB mixers, which use nonlinear heating effects in superconductors near their transition temperature, have become an excellent candidate for applications requiring low noise temperatures at frequencies from 0.5 THz to 12 THz.

Imaging and spectroscopy at terahertz frequencies have great potential for both homeland security and biomedical applications. Terahertz radiation (T-rays) can penetrate clothing and, to some extent, can also penetrate biological materials, and because of its shorter wavelengths offers higher spatial resolution than do microwaves or millimeter waves. Terahertz HEB imagers are designed with frequencies centered at known atmospheric windows with lower signal degradation (the 850 GHz window is one example). Large FPAs, employing tens of HEB elements, promise to provide video rate imaging with superior sensitivities. In addition, certain molecules and chemical reactions exhibit frequency resonances in the terahertz frequency regime. Ultra sensitive and fast spectrometers based on HEB technology promise to provide a diagnosing tool for biological and chemical agents both in the laboratory and in the field.

Terahertz Imager based on HEB Technology

A general scheme for a terahertz imager is shown in Fig.1. Heterodyne detection technique requires a local oscillator (LO) source and an IF amplification chain. Scanning optics allow focusing of the signal beam on a target either in close proximity to the detector or at a large distance (in excess of 25 m). HEB detectors are sensitive enough to resolve temperature differences of less than 1 K in a very short integration time (1 ms). The entire bandwidth (4 GHz) over which the receiver noise temperature is low is detected in the imaging mode, whereas a narrow strip of the bandwidth (250 MHz) is detected and swept as a function of frequency for the spectroscopic detection mode. Preliminary imaging results of terrestrial objects are very promising, and theoretical analysis of a larger array shows that video-rate imaging using the HEB technology is feasible. The challenge is to develop an efficient electronic and optical design, and scalable fabrication method, for multi-element HEB arrays.

We have recently achieved the first demonstration of a low-noise heterodyne FPA operating at a frequency above 1 THz (1.6 THz) [2]. The prototype array has three elements consisting of NbN HEB detectors. The device is fabricated from an NbN film, which has been sputtered onto a silicon substrate. The film thickness is typically 3.5 to 4 nm. A typical device size is 4 μm (width) x 0.4 μm (length). We use a quasi-optical design (antenna and lens) to couple the signal and LO power to the detectors. An operating temperature range for the HEB devices of 4 K to about 6 K is an advantage compared to most other far-infrared (FIR) devices, which require cooling to sub-kelvin temperatures. The HEB chips are directly integrated with monolithic microwave integrated circuits (MMIC) amplifiers in the same mixer block. The optical configuration of the pixel in the array is of the "fly's eye" type, which allows ample space for the other components in the focal plane. The MMICs are coupled through microstrip lines that include a

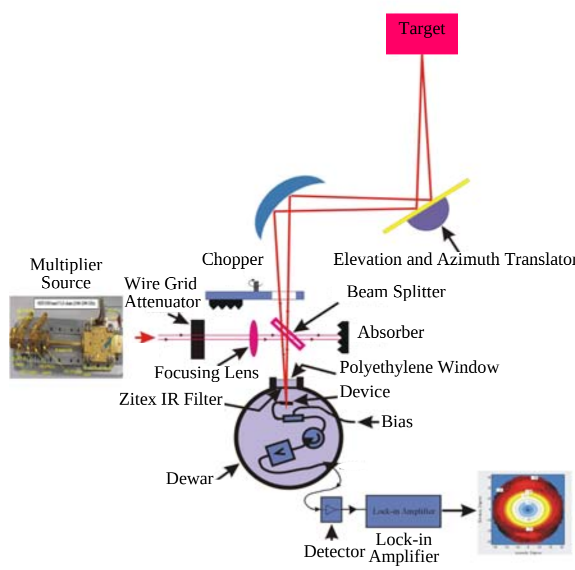

Fig. 1: A diagram of an HEB-based heterodyne imaging and spectroscopic system.

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chip capacitor in series as a DC block. The microstrip lines also function as a matching network between the HEBs and the MMICs. SMA coax lines and connectors allow us to extract the three IF outputs from the sides of this block, and three connectors provide all DC bias lines. Fig. 2 shows photographs of the three-element HEB FPA. Note that no isolator was used in our design.

The performance of the FPA, first of its kind for frequencies above 1 THz, demonstrates the suitability of HEBs as mixer elements in a much larger FPA imager in the future. The prototype FPA we have demonstrated at 1.6 THz indicates that the problems of constructing larger versions of such arrays can be solved.

In order to demonstrate the performance of an HEB-based imager, a single-element HEB mixer detector was used to image the structure shown in Fig. 3 (top) [3]. This prototype imaging system used a standard electromagnetic actuator to rotate a plane mirror by about 30 degrees at a rate of 8 Hz. A target area located about 5 cm from the scanning mirror was selected by the scanning mirror, and focused through two offset-axis paraboloid (OAP) mirrors onto the HEB. The total IF power was filtered to contain the IF band from 1 GHz to 4 GHz and detected in a standard microwave detector. Using a digital oscilloscope, we have recorded linearly scanned images of metal bars seen against a background of room temperature absorber material, as well as human hands against the same background. Fig. 3 (bottom) shows the recorded signal from a scan across the absorber and the metal. Both materials were virtually at the same *physical* temperature but the effective radiative temperature of the metal bar was different by about 15 K. Being able to detect such effective radiative temperature differences is important in security applications. We are developing a fully scannable optics to perform a two-dimensional image of the structure. We will perform imaging measurements at different terahertz frequencies. The lower frequency window around 850 GHz is a good compromise between spatial resolution and the penetration of the terahertz signal.

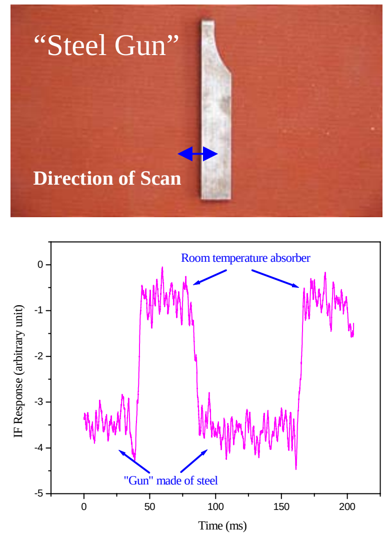

Fig. 3: (top) Photograph of a steel bar on top of an absorber. (bottom) recorded signal of the HEB detector scan across the two materials.

Future Plans

Future designs of FPAs based on HEB technology will have larger number of pixels. We are investigating two different architectures that may each have their advantages for different applications. (1) **A linear array used to provide the horizontal resolution of the object**: In that case the vertical dimension of the object may be scanned using the same type of technique that we used to produce linear images as discussed above. In order to achieve a continuous scan across the object rather than a fixed-rate back-and-forth scan, we will develop an improved scanning scheme using a rotating drum covered with facets that act as mirrors. (2) **A full two-dimensional focal plane array:** This configuration represents a challenging problem in terms of being able to integrate the HEBs and MMIC amplifiers. A new fabrication architecture will be initially implemented for a small number of elements (an FPA of 2x2 elements). The lenses and HEB elements will be configured in the same fly's eye arrangement that we used in the prototype FPA. The MMIC IF amplifiers will be assembled on a separate substrate and contacted through via holes or other methods. This substrate will be attached to a cooling stage at 15-20 K, to ease the cooling requirements on the HEB array itself. The MMIC amplifiers would then be contacted through coplanar waveguide or microstrip lines on flexible Kapton ribbons. In addition, more sophisticated LO injection methods will be utilized. This general architecture is well suited for construction of FPAs with a large number of pixels to produce terahertz imagers and spectrometers with superior sensitivities.

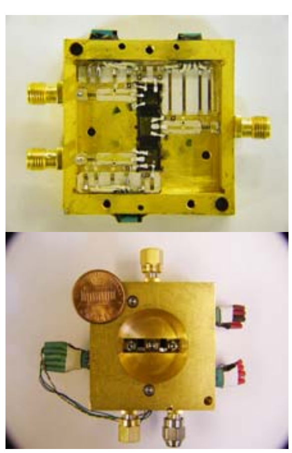

Fig. 2: Photographs of the three-element HEB focal plane array mixer block centered at 1.6 THz.

References

[1] Eyal Gerecht et al., “Deployment of *TREND* – A Low Noise Receiver User Instrument at 1.25 THz to 1.5 THz for AST/RO at the South Pole” 14th Intern. Symp. Space THz Technology, Tucson, Az, April 2003.

[2] Fernando Rodriguez-Morales et al., “A Terahertz Focal Plane Array Using HEB Superconducting Mixers and MMIC IF Amplifiers” Microwave and Wireless Component Letters, IEEE Microwave and Wireless Components Letters, Vol. 15, No. 4, April 2005, pp 199-201.

[3] Eyal Gerecht, Dazhen Gu, Sigfrid Yngvesson, Fernando Rodriguez-Morales, Ric Zannoni, and John Nicholson, “HEB heterodyne focal plane arrays: a terahertz technology for high sensitivity near-range security imaging systems”, SPIE Defense and Security Symposium, Orlando Florida. March 28 – April 1, 2005.