Recent Progress in Commercial Cryogen-free THz Detectors and Large Format Arrays

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***Abstract*— we report recent progress toward commercial cryogen-free THz detector systems. We discuss cryogen free cooling platform options and their applicability not only for traditional semiconductor detectors but also for new superconducting detector technologies in both single pixel and large array format.**

I. Introduction And Background

THE detection of THz frequencies with high sensitivity requires cooled detectors in most circumstances. THz sources are not usually powerful enough to provide the luxury of a high signal-to-noise ratio if room temperature detection methods are used. Passive detection of ambient thermal signals and high atmospheric attenuation places demands on the sensitivity of the detectors used. Although we also report very interesting new developments in room temperature devices [El-Fatimy et.al in this conference] which will provide an imaging capability with high time resolution, such devices will ultimately have a limited sensitivity which precludes wider applicability.

Cryogenic THz detectors are most commonly cooled using liquid helium. Commercial systems like those offered by ***QMC Instruments Ltd.*** [1] offer picoWatt sensitivities and are mature devices. In a research laboratory environment equipped for the use of liquid cryogens the technique is unproblematic for experienced users. For a wider potential civil user community the use of liquid cryogens has a bearing on cost, convenience and safety.

Mechanical coolers have been available for many years that can achieve temperatures of 4K and below, but they have not until recently provided a suitable platform for detectors which are highly sensitive to vibration and are susceptible to electromagnetic interference.

More recent cooling platforms allow many of these problems to be overcome. Moreover, recent advances in detector technology and system architecture offer the possibility of high performance cryogen-free systems in both single pixel and large array format.

II. CRYCOOLERS

We have recently collaborated with ***Cold Edge Technologies Inc.*** to investigate the performance of our traditional semiconductor detectors in their nanometer vibration coolers [2].

Figure 1 shows the noise output spectra of an NTD Germanium bolometer cooled to 4K both in a liquid helium cryostat and in a Cold Edge cooler. The noise level is 20% higher at frequencies above 150Hz when the detector is cooled electrically. This is due to differences in operating temperature in the two situations. In the cryo-cooler the bolometer reaches a lower temperature where its impedance is higher. The expected noise level, dominated by Johnson and phonon contributions, is therefore expected to be higher. The use of a differential amplifier achieves a reduction in noise levels at frequencies below 100Hz.

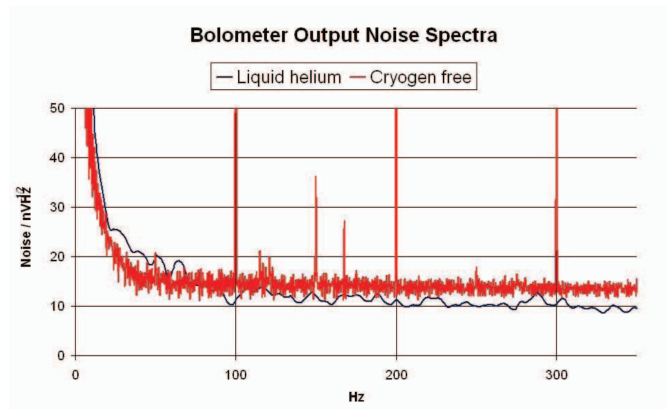

Figure 1 - Noise output spectrum of a Germanium bolometer mounted (blue curve) in a liquid helium cryostat and (red curve) in a Cold Edge cooler.

We now present experimental results of two new detector types and we comment on the cooling platforms used to cool them.

III. Nb BOLOMETERS

We have developed a Niobium voltage-biased superconducting bolometer (VSB). [see D. Hayton et.al. in this conference.]

The VSB detector is operated in a ***Vericold*** CO-5 closed cycle pulse tube cooler (PTC) which offers 250mW cooling power at 4K. Thermal buffering is achieved using a two stage weak thermal link with servo control to give a temperature stability of less than 100µK at approximately 8K over a period of several hours.

TES detectors are significantly less sensitive to vibrations than semiconductor bolometers. ***CryoMech Inc***. gives the maximum displacement of the second stage of their PT410 pulse-tube cooler as 25µm (0.001g acceleration). This can be decreased by an order of magnitude by adding a secondary detector mount stage as described above. The remote motor version of these pulse tube coolers, although more expensive, is desirable to further decrease the amplitude of both mechanical and electrical interferences.

We report the optical performance of the Nb VSB bolometer in more detail elsewhere [Hayton et.al.] To

summarise we observe a system optical NEP of 1.8×10^{-12} $W.Hz^{-1/2}$ and a detector response time τ = 0.6ms (-3dB). We calculate a detector optical NEP of $\sim2\times10^{-13}$ $W.Hz^{-1/2}$. Optimisation of the amplifier and a small design change to the thermistor will reduce the system sensitivity to a level that outperforms the traditional semiconductor device. Furthermore we intend to offer multi-thermistor devices to give optimized performance in variable illumination conditions. The possibility then presents itself to offer devices with sensitivity and speed tailored to individual applications. As the detector is produced using photolithographic techniques we can also envisage the construction of small format arrays.

IV. LUMPED ELEMENT KINETIC INDUCTANCE DETECTORS

The second detector we report is a lumped element kinetic inductance device (LEKID) which was originally conceived by us in 2008 [3] and which has since been successfully demonstrated as an astronomical imaging device in an array format.

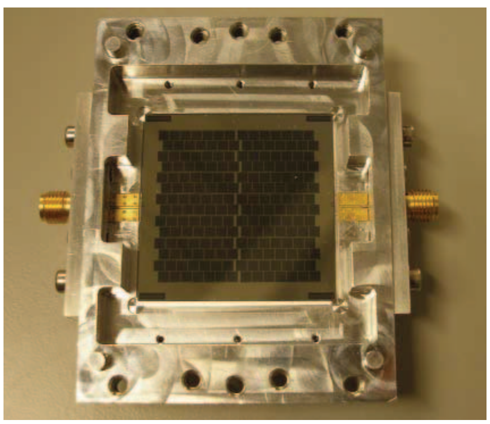

Figure 2 - A 200 pixel LEKID array. Note the single input and output connectors.

The device is a single layer superconducting structure which incorporates both the detecting element and the absorber and which does not require feed-horn or antenna coupling. The LEKID geometry and material choice can be tuned to achieve good optical efficiency across a given frequency band. The LEKID can be multiplexed in the frequency domain allowing a large number of detectors to be read out on a single pair of coaxial cables.

At temperatures well below that of the superconducting transition absorption of THz photons splits Cooper electron pairs into quasi-particles. This results in changes to the surface inductance of the material. In practice the change is very small but it can be accurately measured if the device is fabricated as a high Q microwave resonance circuit (see Fig 3.) The absorption of THz radiation is sensed by looking at the evolution of a microwave tone set to the resonant frequency of the LEKID.

The LEKID devices require no mechanical buffering in a standard pulse-tube cooler and they demonstrate attractive performance characteristics over a wide range of signal modulation frequencies. Tests at 1.5THz reveal a pixel optical NEP of 7x10-16 $W/Hz^{-1/2}$. In order to use such a highly sensitive detector to view ambient temperature objects we will need to reject a large proportion of the signal.

Although the present detectors are operated at sub-K temperatures we see no barrier to their effective application to non-laboratory operating conditions. Our own prototype device is fully automatic and may be remotely operated.

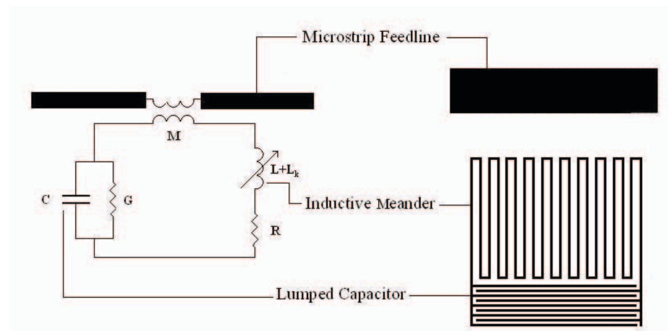

Figure 3 – The LEKID equivalent circuit

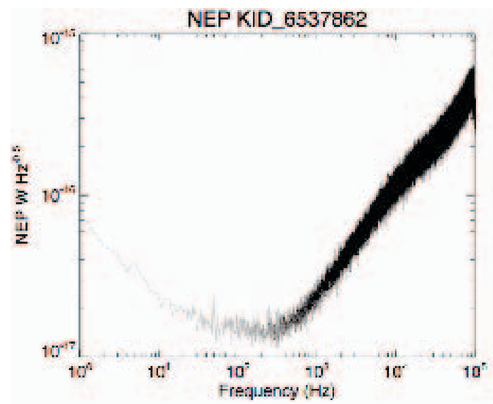

Figure 4 – Electrical NEP measurements for a LEKID designed to operate at 1.5THz.

V. FURTHER WORK

We have reported the effective incorporation of traditional semiconductor broadband THz detectors into electrical cooling platforms. We have also introduced two new detector technologies that will offer improved performance in such environments. These detectors are available as single pixels and as arrays and we are currently building a 1,000 pixel demonstrator instrument for field deployable imaging applications using LEKID detectors.

REFERENCES

[1] QMC Instruments Ltd. School of Physics & Astronomy, Cardiff University, Cardiff, UK. www.terahertz.co.uk
[2] Cold Edge Technologies Inc. www.coldedgetech.com
[3] Doyle, S., Mauskopf, P., Naylon, J., Porch, A., and Duncombe, C., Journal of Low Temperature Physics 151, 530–536 (Apr. 2008)