International Journal of Pure and Applied Mathematics
Volume 117 No. 21 2017, 915-919
ISSN: 1311-8080 (printed version); ISSN: 1314-3395 (on-line version)
url: http://www.ijpam.eu
Special Issue

ijpam.eu

A STUDY ON MICROWAVE BIASING BASED ON NIOBIUM NITRIDE-HEBS

Dr. M. Sudhakar

Professor, Department of ECE

CMR College of Engineering & Technology

vp@cmrcet.org

Abstract : Biasing superconducting Hot Electron Bolometers as terahertz direct detectors by using microwave selections. The Microwave power and frequency have been selected by evaluating the microwave current-voltage curves responses and temperature resistance curves of the Terahertz (THz) direct detectors based on superconducting Niobium Nitride (NbN)Hot Electron Bolometers (HEBs). The non-uniform absorption theory has been used to describe the current jumps in the current – voltage (I-V) curves and the resistance jumps in the resistance –temperature(R-T) curves. The microwave biasing framework may progress the sensitivity, the readout system easier and use less of liquid Helium,and these are all significant for long lasting research. The response time of 86 ps and the noise equivalent power of 1.6pW Hz-1/2 are found for the detectors working at 0.65 THz and 4.2 K.

Keywords:Superconducting Hot Electron Bolometer, Terahertz, microwave biasing, Noise equivalent power

1. INTRODUCTION

Superconducting metal compound hot lepton bolometers are used with success in astronomical observations [1–3] and as ultra-sensitive THz (THz) heterodyne detectors (mixers) with low noise temperature (TN, a couple of times the quantum limit) [4] with the exception of heterodyne detectors, with glorious noise performance and enormous intermediate frequency (IF) gain information measure (GBW) [5], NbN HEBs would be promising as direct detectors for the rate imaging array, wherever heterodyne detectors are terribly troublesome to use, thanks to desires of the native oscillators (LO) and IF amplifiers.

The interaction of microwaves with materials will be classified into the subsequent classes [2]:

1. Opaque materials are usually conducting materials with electron as charge carriers, like metals, that mirror and don't permit magnetic force waves to labor under.
2. Clear materials are low material loss materials or insulating materials, like glass, ceramics and air that mirror and absorb magnetic force waves to a negligible extent and permit microwaves to labor under simply with very little attenuation.
3. Engrossing materials consists of materials whose properties vary from conductors to insulators. they're sometimes cited as ‘lossy materials or high dielectric loss materials’. These materials absorb magnetic force energy promptly and convert it to heat.
4. Magnetic materials like ferrites move with the magnetic element of the nonparticulate radiation and get heated. In microwave process of materials, the interaction between the electrical and field of force elements of microwave and also the materials will result in heating due to material and magnetic losses. Material losses are studied extensively and may be attributed to the distribution of charges or polarization below the influence of associate alternating external field. Material polarization losses embody electronic, orientation (or dipolar), atomic (or ionic) and surface (Maxwell-Wagner). In this paper, Section-1 contains introduction, in section-2 review of literature, in section-3 focuses materials and methods and finally, section-4 contains conclusions.

2. RELATED WORKS

HEBs provide many benefits over SIS junctions and Schottky diodes. The RF (Radio Frequency) resistivity is real and frequency freelance. No LO (Local Oscillator) and RF harmonics area unit made thanks to the slow thermal response of HEBs. The required LO power is incredibly low (nano watts) and is frequency freelance. The frequency of operation of HEBs isn't restricted by the device material. Measuring system operation relies on the robust relationship that some materials exhibit between temperature and resistance. RF radiation, coupled to the absorbent material of a measuring system, is reborn to heat. The absorbent has associate degree negatron heat energy capability cerium, a thermal physical phenomenon G and is connected to a conductor at a shower temperature, Tbath[1]. The increase in temperature of the absorbent material thanks to the incident RF and LO radiation leads to an increase in impedance. This corresponds to an amendment in voltage across the absorbent, if the measuring system is current biased (Ibias). The thermal interval, given by Jth = Ce/G, determines the speed of the measuring system. Hot Electron Bolometers supported superconducting materials have a high sensitivity thanks to the steep dR/dT slope round the vital temperature of the superconductor. By biasing a measuring system around these steep transition, very sensitive, low-noise mixers with wide IF bandwidth can be achieved. Additionally, the warmth capability of the negatron gas is considerably smaller than the warmth capability of the lattice. At superconducting temperatures, to the lattice phonons. As a result, the RF power in the main heats the electrons, leading to larger voltage sensitivity. Gershenzon, et al initial projected the phonon-cooled hot-electron measuring system (p-HEB)[3]. Films of NbN area unit generally deposited by DC thermionic vacuum tube sputter during reactive surroundings of Argon on and element [5]. For phonon-cooled hot-electron measuring system applications, NbN films area unit generally around 4nm thick and have a vital temperature (Tc) between 9K and 11K. The physical layout of a diffusion-cooled measuring system consists of alittle absorbent material, in our case about 10nm thick metal small bridge, contacting the cooling pads on opposite ends. These cooling pads area unit is generally a thick (greater than 50nm) gold structure, and area unit a lot wider than the absorbent material. Throughout operation of a d-HEB[6], photons collected by associate degree antenna heat electrons inside the small bridge. These electrons then chop-chop diffuse out of the small bridge and into the cooling pads that act as heat sinks. The pad-to-pad spacing should be terribly tiny so that electrons might diffuse out of the metal absorbent space and into the gold cooling pads during a time but the electron-phonon interaction time. The particular bridge length is also longer than this, however mustn't exceed the negatron phonon interaction length.

3. MATERIAL AND METHODS

The NbN HEB chip [7]we intend to use consists of a 4 μm wide, 0.4 μm long and 3.5 nm thick NbN bridge on an extremely resistive chemical element (Si) substrate that contains a sensible coefficient within the terahertz band. An exponent spiral two-dimensional antenna with frequency freelance electrical phenomenon and no polarizationis usedto couple terahertz signals to the bridge. The chip is pasted to the rear aspect of a Si hyper-hemispherical lens with a diameter of 10 mm. The Si lens is coated with a 0.65 terahertz antireflection (AR) [10] coating for reducing the optical loss of the incident terahertz signals. An Oxygen free copper holder used to hold theSi lens is put in on the cold plate of the liquid inert gas dewar. The optical window is created of plastic film that contains a sensible coefficient for terahertz radiation with a thickness of 36 μm. Two black polythene films and one G-110 Zitex Polyetrafluoroethylene film are utilized in the dewar input hole at a 77 K thermal shielding frame as infrared filters. In order to calculate the input radiation power victimization Planck's blackbody radiation law, a bit of Virginia Diodes opposition[8]. (VDI) mesh-filter within the holder situated between the dewar window and therefore the HEB holder is employed to outline the input information measure of this technique. The mesh-filter is focused at 0.623 terahertz and yields an information measure of 75 GHz measured by terahertz time-domain mass spectrometer (TDS). In this analysis article, the planning of materials and strategies of projected system as shown in figure-1 is comparable to the microwave stabilization theme setup made in our science lab [10]. A 20 dB electrical device is placed on the cold plate of the dewar for avoiding the 300 Kambientground noise. The circulator is employed to inject microwave to the NbN HEB while not being picked up by the low noise electronic equipment (LNA) directly. The mirrored weak microwave signal from the NbN HEB[9] is amplified by the LNA and demodulated by a microwave square-law detector (power detector), finally fed to a Dynamic Signal Analyser. We tend to additionally connect the microwave output to the spectrum analyser to monitor the mirrored microwave spectrum.

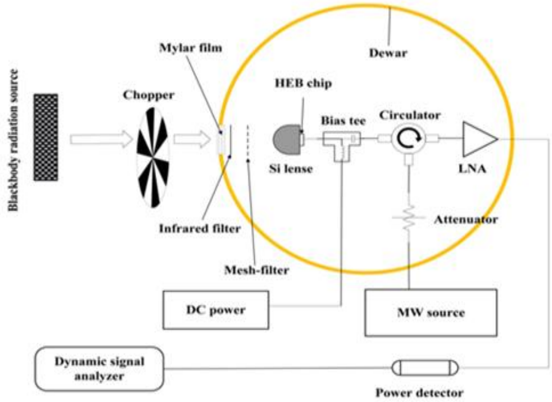

Fig.1 Design of Material and methods of proposed system

In order to evaluate the performance of the NbN HEB, we tend to measure its tennessee at the LO frequency of 0.65 terahertz and bathtub temperature of 4.2 K. The improved Y-factor technique [11] is employed to live the Tennessee for rejection of the direct detection result. The IF output power, illumination unit and Pcold, resembling the recent and cold masses, are measured at constant bias voltage to induce Y = Phot/Pcold. The lowest Tennessee of 500 K (uncorrected, concerning sixteen times the quantum limit) has been obtained at the optimum bias purpose (Vbias = 125 mV, Ibias = 23 μA) that was delineated intimately in [13]. The low Tennessee means that the NbN HEB chip's quality is sweet and therefore the IF circuit matches the chip well. We tend to expect that a coffee noise equivalent power (NEP) of the direct detector victimization this chip with microwave biasing would be achieved.In order to get the latent period of the NbN HEB, we tend to measure the IF GBW of this chip the optimum bias purpose. 2 VDI terahertz sources, with one mounted at 0.65 THz, and therefore the different tuned around 0.65 terahertz. The IF GBW of 1.85 GHz is obtained.

How to select associate acceptable microwave frequency may be a key downside for the microwavebiasing technique. A study of the I–V curves was performed once an NbN HEB was pumped-up by completely different microwave frequencies and power. The two distinct frequency regimes divided by the IF GBW were found by examination the microwave responses of the I–V curves within the microwave vary [12]. Though the precise mechanism continues to be not clear, the investigation of I–V curves pumped-up by completely different frequencies would provide some clues in selecting associate acceptable microwave frequency for biasing the HEB. The proposed microwave responses of the I–V curves with the microwave frequencies round the IF GBW as shown in figures 2, 3, 4 and 5.It's noticeable that in figure 4, a steep current jump of the lowest I–V curve is ascertained once the essential current reaches 75 μA. This development can also be seen in figure 5. There's an outsized blank region in each figures wherever I–V curves cannot reach as a result of slight microwave power changes can cause current jumps and miss this region. As for the heterodyne detection, the optimum bias purpose of NbN HEBs forever seems during this region. This suggests once the microwavefrequency is more than IF GBW, we cannot stabilize the operating state of the NbN HEB within the sensitive region.

I–V curves with a 1.5 GHz injection as shown in figure 2(b) are most almost like the I–V curves with thermal biasing as shown in figure 2. With a 1.5 GHz microwave injection, we are able to scan the full I–V region to seek out a stable bias purpose and obtain very cheap NEP. So as to verify our judgment, we tend to additionally measure the R–T curves of the HEB with1.5 GHz and3 GHz microwave injections as shown in figure 3. Once the injection microwave frequency is about to 3 GHz, each of the 2 R–T curves with microwave injections have steep resistance jumps that correspond to the present jump of the I–V curves obtained in figure 5. Though a pointy transition within the R–T curve means that warmth constant resistance (TCR) [13]which can be used to describe the sensitivity of bolometers, it's diffcult to stabilize the biasing purpose at the resistance jump region within the utilization.

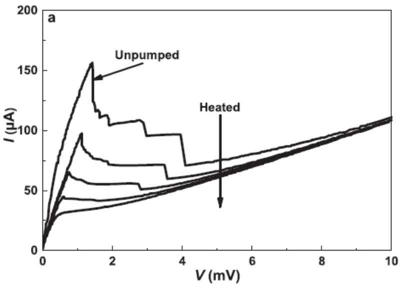

Fig.2 The vertical arrow indicates the direction of increasing bath temperature.

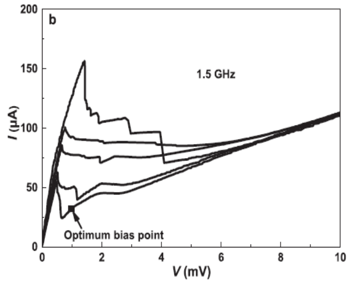

Fig.3 The optimum bias point, where NEP of the direct detector was measured.

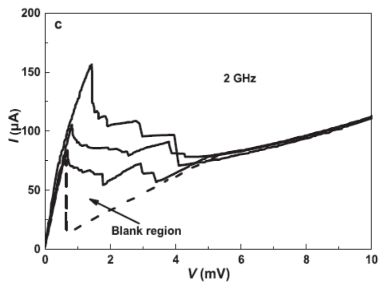

Fig.4 Current jumps (dashed lines) are observed when MW frequencies are higher than the IF GBW.

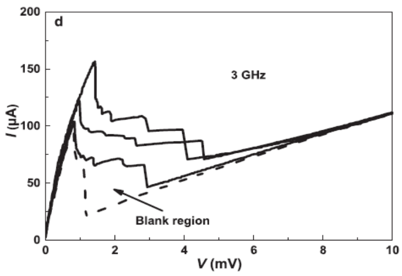

Fig.5 Current jumps (dashed lines) are observed when MW frequencies are higher than the IF GBW.

The non-uniform absorption theory was projected to clarify the

jumps within the R–T curves once the EMW frequency is below the superconducting energy gap frequency [12]. Though the authors solely mentioned the I–V curves and therefore the R–T curves with terahertz radiation, this theory would be fitted to clarify the R–T curves with microwave injection. It's accepted that once the superconductor's temperature rises, the super-conducting energy gap frequency can drop to zero. Relating the center curve in figure 6(b), once the temperature is below concerning 6.6 K, the MW frequency of 3 GHz is below the superconducting energy gap frequency, that the NbN HEB absorption potency is incredibly low and therefore the NbN HEB is unbroken within the superconducting state.Because the HEB temperature rises, the superconducting energy gap frequency can decrease to 3 GHz and so the NbN HEB absorption can increase considerably, that causes the resistance jump. It can also be seen that resistance jumps are additional probably to seem at the upper temperature with a 3 GHz microwave injection compared to the R–T curves with 0.5 GHz MW injections in figure 6(a). We tend to attribute this difference to the unknown heating mechanism associated with the IF GBW that deserves more in-depth studies within the future.

When the injected microwavefrequency is 1.5 GHz, the 2 R–T curves while not resistance jumps have trickster transitions compared to the R–T curve while not microwave injection. The next responsivelyis achieved at Tc of the R–T curve with acceptable microwave power injection compared to the thermal biasing technique. Supported the discussions higher than, we chose 1.5 GHz MW to bias the HEB as an on the spot detector and expect a more robust performance compared to the thermal biasing technique. In order to research the operating theme of this technique, we tend to use a VDI terahertz supply with a frequency of 0.65 terahertz and low emission power as a weak signal, which may be detected, however don't modify the present at the optimum bias purpose, before of the dewar window. Figure-4 is that the output signal's spectrum from the LNA output port. The middle frequency is concerning 15 GHz (a slight deviation from 1.5 GHz is caused by the microwave source), that is in step with the injection microwave frequency. 2 sidebands situated in either side and therefore the offset frequency is that the same as modulation frequency Fm. Once we decrease the modulation frequency of the chopper, 2 sidebands move toward the middle peak and therefore the offset frequency keeps constant as Fm[15]. From this development we canconclude that the side-bands are caused by the incident signal that is modulated by the chopper. The modulated incident terahertz signal changes the HEB electrical phenomenon that the reflection constant of the microwave network is additionally modified and therefore the microwave signal mirrored by the HEB is indirectly modulated by the chopper.

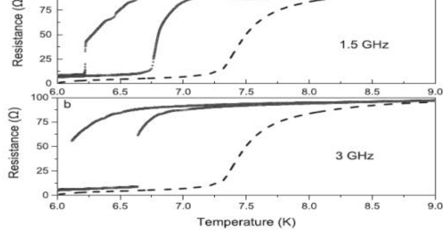

Fig.6 R–T curves with (circles) and without (dashed lines) MW

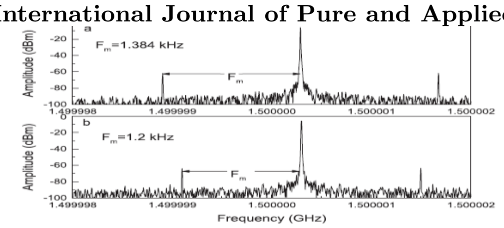

Fig.7 Spectra of the output power measured at the output of the LNA with Fm at 1.384 kHz (a) and 1.2 kHz (b). The bias setting was injections.

NEP is one amongst the key parameters of the direct detectors. So as to live the NEP of the NbN HEB direct detector victimization microwave biasing, an electromagnetic wave supply with temperature set at 1073 K was placed before of the dewar window with a chopper between them. With the input information measure outlined by the VDI mesh-filter, the input radiation power of 0.8 nW is calculated by victimization Planck's electromagnetic wave law. The chopping frequency is ready to 1.37 kHz. So as to get all-time low NEP, we tend to scan all regions underneath the un-pumped I–V curve and find the optimum bias purpose that is marked in figure 3. At this bias purpose, the digital spectrum at 1.37 KHzto concerning 508 times the baseline of the noise voltage spectrum with resolution information measure of one cycle per second. we tend to comprehend the NEP is 508 times below 0.8 nW, therefore, the NEP at the optimum bias purpose is 1.6 pW $Hz^{-1/2}$ that is healthier than the thermal biasing NbN HEB direct detector's performance [6].

Conclusions

This research work has proposed the microwave responses of the I–V curves and the R–T curves. The non-uniform absorption theory, shows the current jumps in the I–V curves and the resistance jumps in the R–T curves well and good. A suitable frequency of Microwave was chosen to Terahertz direct detectors based on superconducting Niobium Nitride Hot Electron Bolometers [14]. The injected microwaveserves two purposes, for biasing the Hot Electron Bolometersto the optimum point and reading out the small impedance change of the Hot Electron Bolometerscaused by the input Terahertz signals variation. These works monitored the output microwave power from the low noise amplifier and get the research work design of this method. The noise equivalent power of 1.6 pW $Hz^{-1/2}$ are obtained and can be expected to be improved by optimizing the readout circuit in the near future.

References:

[1] R.F. Schiffmann. Ceramic Transactions Vol. 80. D.E. Clark, W.H. Sutton and D.A. Lewis(eds). Westerville, Ohio: The American Ceramic Society. 41-60. 1997.
[2] F. Gronwald and J. Nitsch. IEEE Antennas Propag 43: 64-79. 2001.
[3] Y.V. Bykov, K.I. Rybakov and V.E. Semenov. J Phys D: Appl Phys 34: R55-75. 2001.
[4] A.J. Papworth, D.K. Agrawal and J. Cheng. In Proc. EMAG 2001, Institute of Physics Conf. Ser. No. 168. 5-7 September, 2001. Dundee, UK. pp. 199-202.
[5] Chen J, Liang M, Kang L, Jin B B, Xu W W, Wu P H,Zhang W, Jiang L, Li N and Shi S C 2009 IEEE Trans.Appl. Supercond. 19 278–81.
[6] Kroug M, Cherednichenko S, Merkel H, Kollberg E,Voronov B, Gol'tsman G, Huebers H W and Richter H 2001IEEE Trans. Appl. Supercond. 11 962–5.
[7]Ren Y, Miao W, Yao Q J, Zhang W and Shi S C 2011 Chin. Phys. Lett. 28 010702.
[8] Skalare A, McGrath W R, Bumble B, LeDuc H G, Burke P J, Verheijen A A, Schoelkopf R J and Prober D E 1996 Appl.Phys. Lett. 68 1558–60.
[9]Jiang Y, Jin B B, Xu W W, Kang L, Chen J and Wu P H 2012 Science China-Information Sciences 55 64–71.
[10] S L Jiang et al. Appropriate microwave frequency selection for biasing superconducting hot electron bolometers as terahertz direct detectors, Supercond. Sci. Technol. 30 (2017) 044004 (5pp).
[11]Gousev Y P, Goltsman G N, Karasik B S, Gershenzon E M, Semenov A D, Barowski H S, Nebosis R S and Renk K E 1996 Int. J. Infrared Millimeter Waves 17 317–31.
[12] Lobanov Y, Tong E, Blundell R, Hedden A, Voronov B and Gol'tsman G 2011 IEEE Trans. Appl. Supercond. 21 628–31.
[13] Miao W, Zhang W, Zhong J Q, Shi S C, Delorme Y, Lefevre R,Feret A and Vacelet T 2014 Appl. Phys. Lett. 104 052605.
[14]Jiang S L, Jia X Q, Jin B B, Kang L, Xu W W, Chen J and Wu P H 2015 40th Int. Conf. on IR, MM and THz Waves (https://doi.org/10.1109/IRMMW-THz.2015.7327514).
[15] R.B. Bass, "Hot-Electron Bolometer Fabrication," Presented to the Faculty of theUniversity of Virginia for a PhD Qualifying Exam, February 2003.