NbAu Bilayer Hot Electron Bolometer

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Abstract

Hot Electron Bolometer (HEB) mixers based on NbAu bilayers have been reported recently. In this paper, a model is presented to quantitatively explain the device performance. Proximity effect suppresses superconductivity under the antenna pads. In a part of the bolometer bridge, the critical temperature is reduced by this effect. Solving a heat balance relation indicates, that NbAu bilayer HEB have a comparably bad conversion gain (about -20dB compared to -17dB for Nb) since a considerable fraction of heating power is lost in and close to the antenna pads.

1 Introduction

Analyzing point-HEBs, it has been concluded that the receiver noise temperature depends on the square of the critical temperature ([1], [2]). Large efforts have been undertaken to reduce the critical temperature of the HEB material (e.g. Al [3]). Al HEB have failed and Andreev reflection has emerged as a bottleneck for Nb HEB. Recently NbAu bilayers have been proposed to optimize the critical temperature without changing other material properties substantially [4]. NbAu HEB have not yet shown the expected reduction in noise temperature. This is due to strong Andreev reflection and due to the absence of contact resistance. Controlling contact resistance under the antenna pads is crucial to achieve low noise and low power HEB mixers. For in-situ Au top layers the electron transmissivity of the interface is large giving rise to proximity effect. Eventually the critical temperature under the antenna pads becomes lower than the bath temperature. This normal zone extends then into the bridge efficiently reducing conversion gain.

2 Device Modelling

The full details of HEB modelling are found in [5]. There is a fundamental difference between bilayer HEB and other types of HEB found in the presence of contact resistance effects. Covering a very thin superconducting film with a normal metal suppresses the superconductivity in the film by proximity effect. This effect depends strongly on the quality of the contact - in-situ contacts (as in this case) or excessive cleaning of the superconductor layer prior to film deposition yields very good contacts and therefore a large proximity effect. This reduction of the critical temperature under the pad is partially visible in a region of the bridge close to the pads (at a distance $\lambda_q^\star$ [6]) where the critical temperature of the HEB bridge smoothly changes from its value at the center to the value under the pads. An empirical model for this proximity effect is to perform a polynomial fit of the critical temperature profile. The parameter to be fitted is β in the following template:

$$T_c(x) = \left(T_{c0} + (T_c - T_{c0}) \left(1 - \left(\frac{|x|}{L} \right)^{\beta} \right) \right) \tag{1}$$

Fit data are obtained using R(T) curves with two transition temperatures - one in the center (allowing to extract T_c) and another under the pad (yields $T_{c,0}$). Values for the exponent β are found by a curve fit. For NbAu one obtains $\beta \approx 7...8$, and for Nb , NbN and NbTiN $\beta \approx 15...25$. This critical temperature profile is used in the heat balance relation instead of a constant critical temperature.

3 Theory versus Experiment

NbAu HEB have been produced at DIMES in Delft (the Netherlands). Results for the proximity effect on these films are found in literature [?]. Devices have been tested at DIMES [4]. In Figure 1, this published material is compared with calculated results.

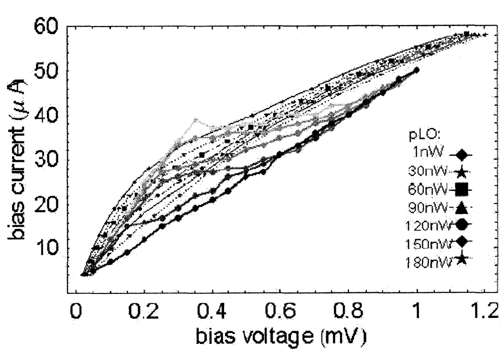

Figure 1: Measured and calculated IV curves.

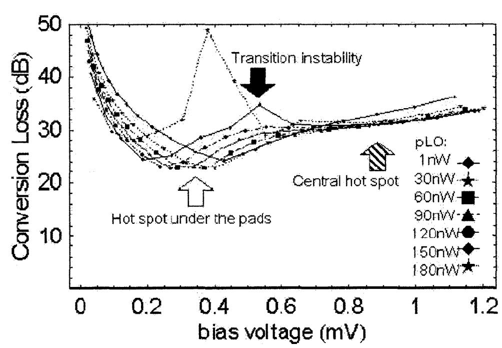

Figure 2: Conversion loss versus bias voltage curves.

In Figure 1, an umpumped and a series of pumped curves for NbAu HEB are compared with model calculations. No measured data on RF properties of these devices is available at this moment. Theoretical results for the conversion loss are shown in Figure 4. Clearly two distinct regimes (without and with a central hot spot) can be seen. Both regions are separated by a transition instability where the hot spot configurations change from one to another without an change in device resistance. Theoretical results for the noise are shown in Figure 3. For the same bias points the IF bandwidth is shown in Figure ??.

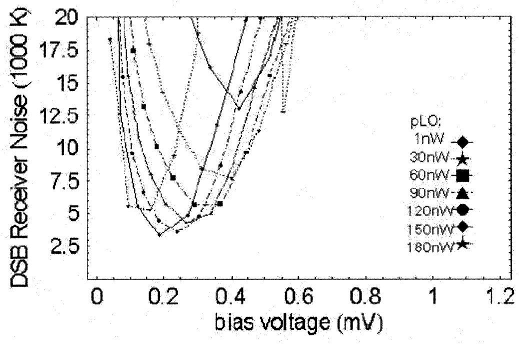

Figure 3: DSB Receiver Noise Temperature versus bias voltage

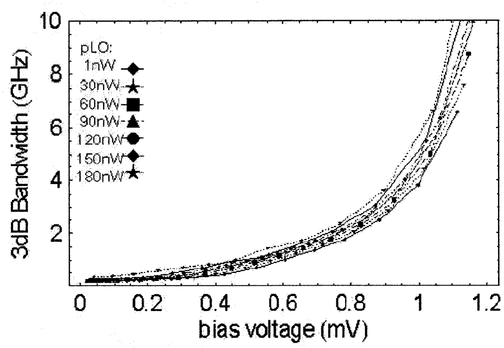

Figure 4: IF bandwidth versus bias voltage curves.

4 Conclusion

NbAu HEB are be not very suited as Terahertz mixers. Nevertheless they have proven to be a valuable tool to study the influence of contact resistance on the bolometer performance - too good contacts destroy indeed the HEB noise performance by creating additional parasitic hot spots. Extremely bad contacts result in a large zone where the RF current is squeezed from the Au top layer to the superconductor yielding a large effective bolometer size requiring a lot of LO power to be pumped properly. As a conclusion, contacts under the antenna pads must be controlled bad. Excessive cleaning of the superconducting film prior to adding the top layer is detrimental for the performance.

The authors want to thank M. Hajenius and J.R.Gao (DIMES/Delft) for sharing the measurement data and many fruitful discussions.

References

[1] H. Ekstrom, B. Karasik, E. Kollberg, and K. Yngvesson, "Conversion gain and noise of niobium superconducting hot-electron-mixers," *IEEE Transactions on Microwave Theory and Techniques* **43**, p. 938, 1995.

[2] B. Karasik, M. Gaidis, W. McGrath, B. Bumble, and H. LeDuc, "A low-noise 2.5 thz superconductive nb hot-electron mixer," *IEEE Transactions on Applied Superconductivity* **7**, p. 3580, 1997.

[3] I. Siddiqi, A. Verevkin, D. Prober, A. Skalare, B. Karasik, W. McGrath, P. Echternach, and H. LeDuc, "Noise and conversion efficiency of aluminum superconducting hot-electron bolometer mixer," *IEEE Transactions on Applied Superconductivity* **11**, p. 958, 2001.

[4] X. Lefoul, P. Yagoubov, M. Hajenius, W. Vreeling, W. Ganzevles, J. Gao, P. deKorte, and T. Klapwijk, "Dc and if bandwidth measurements of superconducting diffusion cooled hot electron bolometer mixers based on nbau bilayers," *Proceedings of the 13.th Terahertz Workshop Cambridge MA.* , pp. 369–372, 2002.

[5] P. Khosropanah, Merkel, S. Cherednichenko, J. Baubert, T. Ottosson, and E. Kollberg, "Nbtin and nbn hot electron bolometer," *Proceedings of the 14.th Terahertz Workshop, Tucson* , 2003.

[6] D. Wilms-Floet, *Ph.D. Thesis: Hotspot mixing in THz Nb superconducting HEB mixers*, Dept. of Applied Physics, RU Groningen, Groningen, The Netherlands, 2001.