Impact of operating conditions on noise and gain bandwidth of NbN HEB mixers

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Hot-electron bolometer mixers (HEB's) are the most promising devices as mixing element for terahertz spectroscopy and astronomy at frequencies beyond 1.4 THz. They have a low noise temperature and low demands on local oscillator (LO) power.[1,2] An important limitation is the IF bandwidth, of the order of a few GHz, and which in principle depends on energy relaxation due to electron-phonon processes and on diffusion-cooling. It has been proposed by Prober that a reduction in length of the HEB would lead to an increased bandwidth.[3] This appeared to be achieved by Tretyakov et al by measuring the gain bandwidth close to the critical temperature of the NbN.[2] Unfortunately, the noise bandwidth of similar devices operated at temperatures around 4.2 K appear not depend on the length. The fundamental problem to be addressed is the position-dependent superconducting state of the HEB-devices under operating conditions, which determines the conditions for the cooling of the hot quasiparticles. Some progress has been made by Barends et al in a semi-empirical model to describe the I,V curves under operating conditions at a bath temperature around 4.2 K.[4] In more recent work Vercruyssen et al have analyzed the I,V curve, without any LO-equivalent bias, of a model NSN system.[5] This work suggests that the most appropriate model for an HEB under operating conditions is that of a potential-well in the superconducting gap in the center of the NbN, analogous the bimodal superconducting state described by Vercruyssen et al. Hot quasiparticles in the well can not diffuse out and can only cool by electron-phonon processes, those with higher energies than the heights of the walls of the well can diffuse out. Using this working hypothesis we have carried out experiments on a sub-micrometer NbN bridge connected to a gold (Au) planar spiral antenna. An *in situ* process is used to deposit Au on NbN. The Au is removed in the center to define the uncovered NbN, which will act as the superconducting mixer itself. The antenna is deposited on the remaining Au layer on the NbN. The Au contacts suppress the energy gap of the NbN film located underneath the gold layer[7,8]. The measured resistive transition is shown in Fig.1. It clearly shows a T_c of the bilayer at 6.2 K and the resistive transition of the NbN itself around 9 K. In addition we show the measured noise bandwidth (red squares) for different bath temperatures. Clearly the noise bandwidth increases strongly by increasing the bath temperature from 5 K to 8 K, up to 13 GHz. We interpret this pattern as evidence for improved out-diffusion of hot electrons due to normal banks and a shallow superconducting potential well compared to k_BT. As expected the noise temperature in this regime is much bigger than when biased at 4.2 K.

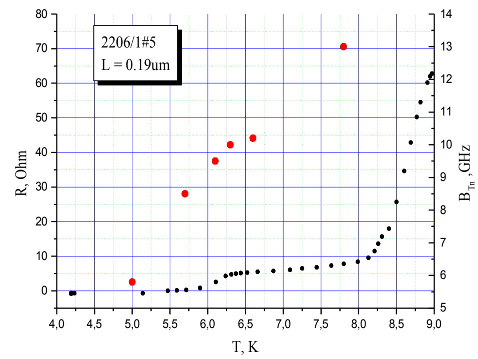

Fig 1. Temperature dependence of HEB mixer resistivity — black symbols, temperature dependence of noise bandwidth HEB mixer – red symbols.

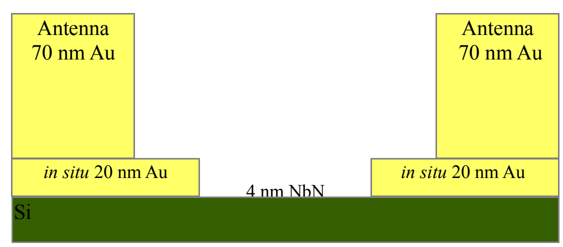

Fig 2. The cross-section of the device, showing the thick Au-NbN and the bare NbN layers.

References

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