Quantum transport at Dirac point enables graphene for terahertz heterodyne astronomy

Sergey Cherednichenko[1], Andrey Danilov[1], Dmitriy Golubev[3], Hans He[1], K.H. Kim[1], Rositsa Yakimova[4], Floriana Lombardi[1], Thilo Bauch[1], Samuel Lara-Avila[1,2] and Sergey Kubatkin[1]

Further leaps in astronomy demand new detector materials and devices reaching the fundamental detection limit[1]. Superconducting hot-electron bolometer (S-HEB) mixers form the baseline for modern astronomical receivers above 1 THz. In these, the wave beating between the Local Oscillator (LO) and the THz signal causes temperature oscillations in a metal around the transition temperature, at the Intermediate Frequency (IF), enabling read-out through changes in electrical resistance R (resistive read-out) as long as the temperature can follow the signal modulation. Despite huge efforts, the instantaneous bandwidth in practical niobium nitride (NbN)-based S-HEB mixers does not exceed 4-5GHz, limited by the electron temperature relaxation rates. The search for new materials lead to MgB2 devices,[2] where an 11 GHz bandwidths and a 1000K noise temperature are possible but at the expense of high LO power requirements, which is particularly detrimental for array applications. Beyond superconducting materials, charge-neutral graphene has been discussed as an ideal platform for terahertz bolometric direct detectors due to its small heat capacity and weak electron-phonon coupling. However, absence of large-area graphene homogeneously doped to Dirac point hinders any prospects for practical detectors in astronomy and other sensing applications. Furthermore, negligible temperature dependent resistance has kept this approach as not acceptable for bolometric mixers where voltage read-out is required.

Here we investigate graphene that is doped to the Dirac point by assembly of molecular dopants on its surface with a high uniformity across the wafer and the long-though temperature-dependent resistance. With the resistance dominated by quantum localization, and thermal relaxation of carriers governed by electron diffusion, we demonstrate a graphene bolometric terahertz mixer with a gain bandwidth (presently) of 9 GHz (relaxation time 20ps) (see Fig.1) and a mixer noise temperature of 475 K. We conclude that with the present quality of graphene, optimization of the device layout will result in a mixer noise temperature as low as 36 K and a gain bandwidth exceeding 20 GHz, with a Local Oscillator power of < 100 pW for operation temperatures <1K. Given the scalability of the material and in conjunction with emerging quantum-limited amplifiers in the GHz domain, we envisage large arrays of quantum–limited sensors in the THz domain for radio astronomy, potentially surpassing superconductor-based heterodyne detectors.

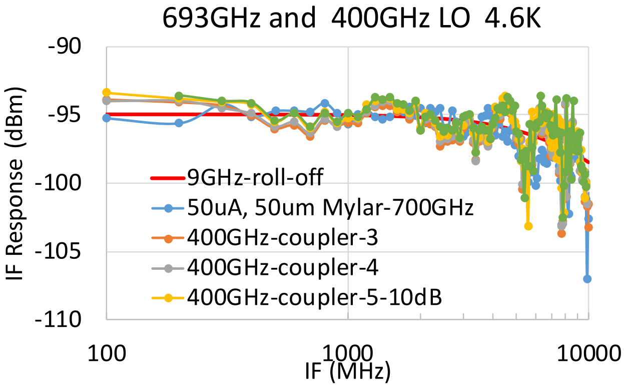

Fig. 1. Intermediate frequency response of graphene bolometric mixer. LOs at 693GHz and 400GHz were utilized with matching tunable signal sources. The gain of the IF chain has been removed from the measured data. The residual ripples are probably coming from the long bonding wires and the mixer unit itself.

REFERENCES

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[1] Department of Microtechnology and Nanoscience, Chalmers University of Technology, SE-412 96, Gothenburg, Sweden.

[2] National Physical Laboratory, Hampton Road, Teddington, TW11 0LW, UK

[3] Department of Applied Physics, Aalto University, FI-00076 Aalto, Finland.

[4] Department of Physics, Chemistry and Biology, Linkoping University, S-581 83, Linköping, Sweden.

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