Superconducting diamond films as perspective material for direct THz detectors

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Abstract— Superconducting films with a high resistivity in the normal state have established themselves as the best materials for direct THz radiation sensors, such as kinetic inductance detectors (KIDs) [1] and hot electron bolometers (nano-HEBs) [2]. The primary characteristics of the future instrument such as the sensitivity and the response time are determined by the material parameters such as the electron-phonon (e-ph) interaction time, the electron density and the resistivity of the material. For direct detectors, such as KIDs and nano-HEBs, to provide a high sensitivity and low noise one prefer materials with long e-ph relaxation times and low values of the electron density.

As a potential material for THz radiation detection we have studied superconducting diamond films. A significant interest to diamond for the development of electronic devices is due to the evolution of its properties with the boron dopant concentration. At a high boron doping concentration, $n_B \sim 5\cdot 10^{20}$ cm^{-3}, diamond has been reported to become a superconducting with T_c depending on the doping level. Our previous study of energy relaxation in single-crystalline boron-doped diamond films epitaxially grown on a diamond shows a remarkably slow energy-relaxation at low temperatures. The electron-phonon cooling time varies from 400 ns to 700 ns over the temperature range 2.2 K to 1.7 K [3]. In superconducting materials such as Al and TiN, traditionally used in KIDs, the e-ph cooling times at 1.7 K correspond to ~20 ns [4] and ~100 ns [5], correspondingly. Such a noticeable slow e-ph relaxation in boron-doped diamond, in combination with a low value of carrier density ($\sim 10^{21}$ cm^{-3}) in comparison with typical metals ($\sim 10^{23}$ cm^{-3}) and a high normal state resistivity (~1500 μΩ·cm) confirms a potential of superconducting diamond for superconducting bolometers and resonator detectors. However, the price and the small substrate growth are of single crystal diamond limit practical applications of homoepitaxial diamond films. As an alternative way with more convenient technology, one can employ heteroepitaxial diamond films grown on large-size Si substrates.

Here we report about measurements of e-ph cooling times in superconducting diamond grown on silicon substrate and discuss our expectations about the applicability of boron-doped diamond films to superconducting detectors. Our estimation of limit value of noise-equivalent power (NEP) and the energy resolution of bolometer made from superconducting diamond is order 10^{-17} W/Hz$^{1/2}$ at 2 K and the energy resolution is of 0.1 eV that corresponds to counting single-photon up to 15 um. The estimation was obtained by using the film thickness of 70 nm and $\rho \sim 1500$ μΩ·cm, and the planar dimensions that are chosen to couple bolometer with 75 Ω log-spiral antenna. Although the value of NEP is far yet from what might like to have for certain astronomical applications, we believe that it can be improved by a suitable fabrication process. Also the direct detectors, based on superconducting diamond, will offer low noise performance at about 2 K, a temperature provided by inexpensive close-cycle refrigerators, which provides another practical advantage of development and application of these devices.

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