# Can NbN films on 3C-SiC/Si change the IF bandwidth of hot electron bolometer mixers?

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***Abstract*— We realized ultra thin NbN films sputtered grown on a 3C-SiC/Si substrate. The film with a thickness of 3.5-4.5 nm shows a $T_c$ of 11.8 K, which is the highest $T_c$ observed among ultra thin NbN films on different substrates. The high-resolution transmission electron microscopy (HRTEM) studies show that the film has a monocrystalline structure, confirming the epitaxial growth on the 3C-SiC. Based on a two-temperature model and input parameters from standard NbN films on Si, simulations predict that the new film can increase the IF bandwidth of a HEB mixer by about a factor of 2 in comparison to the standard films. In addition, we find standard NbN films on Si with a $T_c$ of 9.4 K have a thickness of around 5.5 nm, being thicker than expected (3.5 nm).**

***Index Terms*—Hot electron bolometer mixer, thin superconducting films, NbN film, and 3C-SiC**

NbN hot electron bolometer (HEB) mixers in combination with THz quantum cascade lasers[1] are a promising heterodyne detection technology for future astronomic and Earth's science space missions for the frequency range from 2 to 6 THz. However, the limited IF gain bandwidth of HEB mixers based on standard NbN thin film on a Si substrate tends to restrict their application[2,3]. It is highly desirable to develop new ways to enlarge the bandwidth. Although replacing standard Si by MgO as "substrate", the NbN films grown epitaxially have an increased critical temperature ($T_c$)[4]. They have demonstrated an improved IF bandwidth from 3 GHz to 4.5 GHz. But MgO is hygroscopic and is therefore incompatible with space applications.

We realized, for the first time, ultra thin NbN films on a 3C-SiC buffer layer[5] on a Si substrate, which are sputtered grown at a substrate temperature of 800 °C. The 3C-SiC buffer layer was produced at Case Western Reserve University (USA), which is heteroepitaxially grown on a Si substrate and is 1 μm thick, while the NbN films were realized at Moscow State Pedagogical University (Russia), Due to the perfect lattice matching, a 3.5-4.5 nm thick film shows a $T_c$ of 11.8 K, which is the highest $T_c$ observed among ultra thin NbN films. The measured resistance versus temperature is given in figure 1. The monocrystalline structure and the thickness of the NbN film are evaluated through high-resolution transmission electron microscopy (HRTEM). Figure 2 shows a HRTEM micrograph of the NbN film on a 3C-SiC buffer layer, together with a zoom view. We also find a lattice constant of 4.36Å for the 3C-SiC layer and 4.39Å for the NbN thin film on the SiC layer. Note that the first realization of NbN films on 3C-SiC buffer layer was reported by Shoji *et al*[6]. However, those are thick films with a thickness of 100 nm.

Our HRTEM studies, as an offshoot, also show that standard NbN films on Si with a $T_c$ of 9.4 K have a thickness of around 5.5 nm, being thicker than 3.5 nm, which is expected from the sputtering rate calibrated from thick NbN films[4]. Figure 3 shows two HRTEM micrographs of NbN on Si, one being for the film with a $T_c$ of 9.4 K and the other being for the film with a slightly higher $T_c$ (9.8 K). The latter turns out to be around 6 nm thick. As indicated in the inset, such films have a polycrystalline structure.

Based on a two-temperature model[7,8] and input parameters from standard NbN films on Si, simulations predict that the new film can increase the IF bandwidth by at

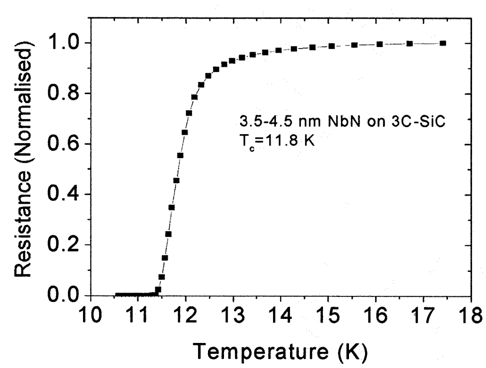


FIG.1. Measured resistance as a function of temperature for an ultra thin NbN film epitaxially grown on a 3C-SiC buffer layer on a Si substrate.

least a factor of 2 in comparison to NbN films on Si. The result is shown in figure 3. The physical reason is that the higher $T_c$ favors a shorter thermal time constant because of

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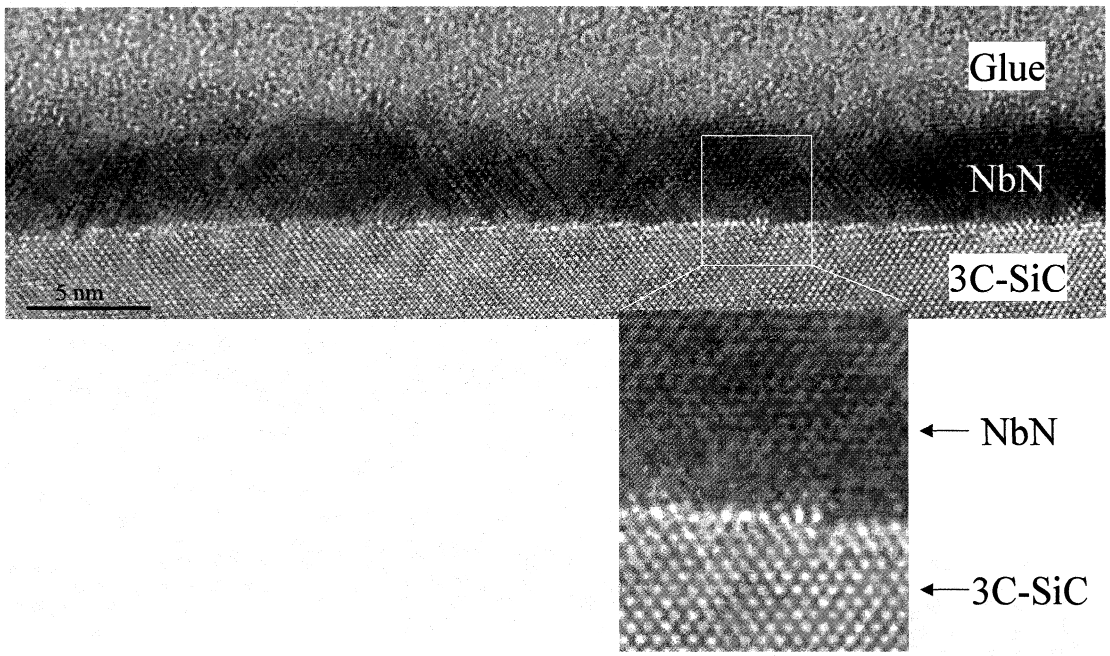


FIG.2. HRTEM micrograph of a thin NbN film grown on a 3C-SiC buffer layer. From the top, the glue, NbN film, and SiC layer are seen. The glue is used to prepare the specimen for HRTEM inspection. A zoom view of the NbN film on 3C-SiC, which illustrates a monocrystalline structure of the NbN layer.

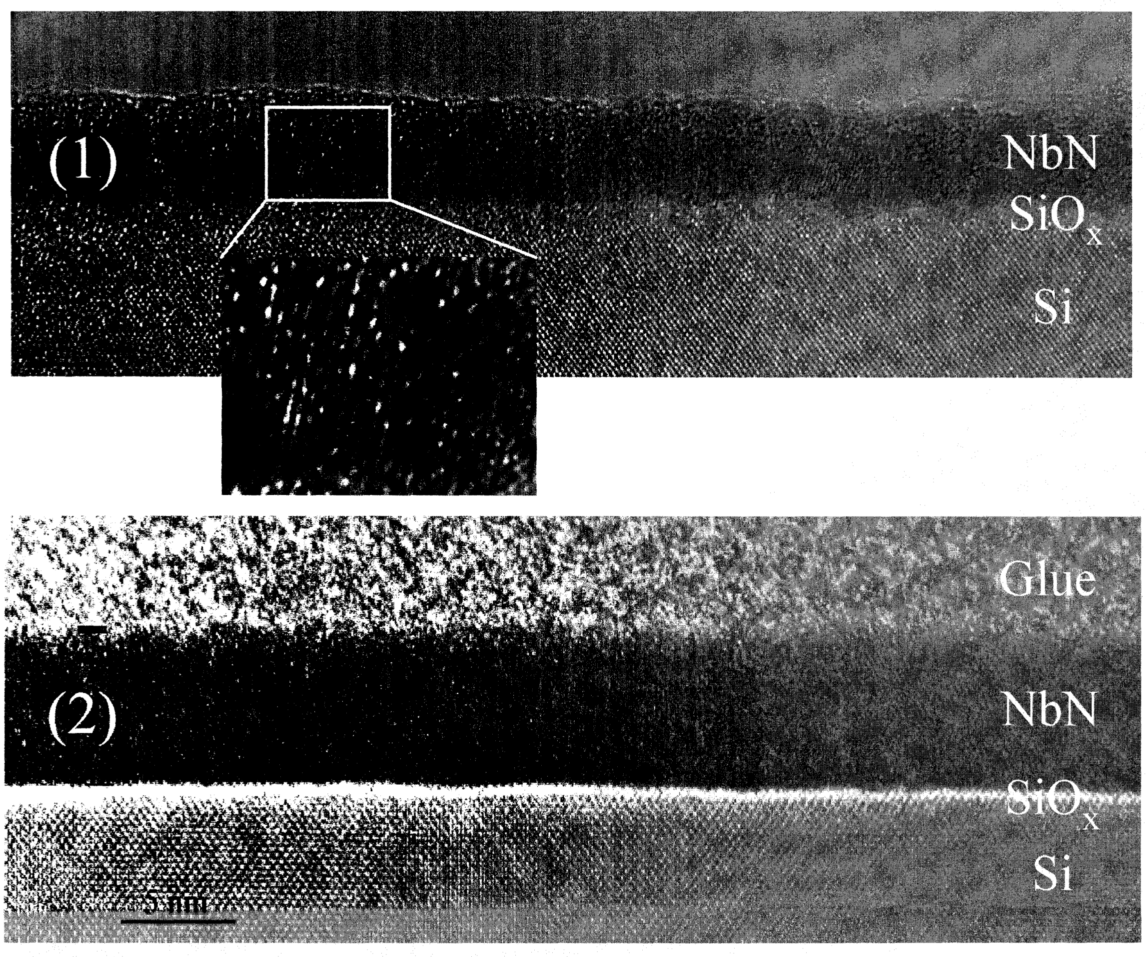


FIG.3. HRTEM micrographs of two thin NbN films grown on a Si substrate with a remaining native oxide layer. The top one ( film 1) is for the film with a $T_c$ of 9.4 K. The glue used to prepare the specimen for HRTEM inspection is removed. The zoom shows a polycrystalline structure of the NbN. The bottom one ( film 2) is for the film with a $T_c$ of 9.8 K. The glue in this case is remained.

the temperature dependence of the electron and phonon specific heat, and the thinner film favors a shorter phonon escape time to the substrate. In this simulation, we ignore the fact that the electron-phonon interaction time can also be film property dependent, in which a cleaner film can result in weaker electron-phonon interaction.

In addition, knowing the thickness correctly is crucial to simulate the measured IF impedance and bandwidth using the two-temperature model[9] and is also valuable for correctly modeling[10] and further improving HEBs.

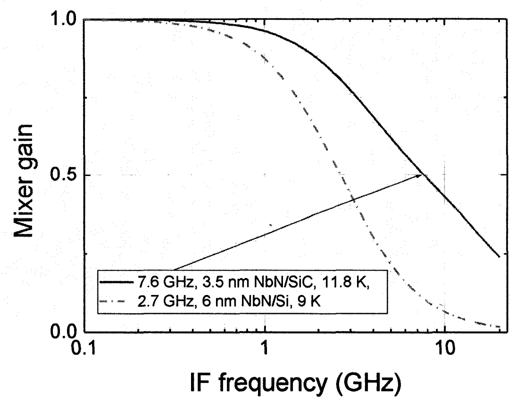


FIG.4. Calculated IF gain (normalized) versus intermediate frequency (IF) based on a two-temperature model for the NbN film on 3C-SiC and the film on Si substrate.

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