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Extended Abstract

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Using of radiation technique to transform superconductive NbN thin film to metal or insulator state to form functional nano elements for cryo-electronic devices

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This work describes the way to transform niobium nitride (NbN) superconductive thin film to metal or insulator state under low energy ion beam irradiation. The radiation technique of selective changing of atomic composition of thin films under ion beam irradiation was designed in NRC Kurchavov Institute and was used for different nano technology applications (patterned magnetic media, metal or insulator nanowires production, etc.). The selective displacement of atoms (SDA) technique was used to displace some of nitrogen atoms in NbN (cubic, a=0.4394 nm) to oxygen atoms under composite ion beam irradiation. As a result NbNO monoclinic phase (P21/c(14), a=0.4977 nm, b=0.50217 nm, c=0.52053 nm, α=γ=90o, β=100o) was formed at 12 dpa dose range. This phase characterized with metal-type electrical conductivity at 4.2 K temperature and was used to produce integrated cryo-resistive elements. Metal phase formation was proved by electrical measurements and HRTEM structure analysis. Further increasing of the ion irradiation dose was lead to full displacement of nitrogen atoms to oxygen atoms and initial superconductive film was transformed to insulator amorphous film of Nb2O5. The formation of insulator film was proved by electrical measurements, XPS and EELS techniques. Insulator phase was used to form on chip-integrated cryo-nanocapacitor elements. We also used this insulator phase to form the nanoscale gap in planar Josephson junction (SIS) structures. In all cases to implement the ion-irradiation techniques in the field of nanotechnology, the protective mask must be used to get desirable properties transformation in different parts of on-chip design structure. We have developed some protective layers on the top of polymethyl methacrylate (PMMA) electron resist film to increase the radiation stability of the nano-mask during irradiation.

The paper considers the use of low-energy composite ion beam radiation to change the superconducting properties of ultrathin (5 nm) films of niobium nitride. It was found that the effect of ion irradiation causes a reduction in the superconducting transition temperature and increasing the resistivity of the film in the normal state. We studied the electrical properties of the irradiated films with doses up to 12.6 d.p.a. (for Nitrogen) in the temperature range from 2 to 300 K. It is found that at a temperature of 4.2 K films irradiated with doses of 12.6 d.p.a. and above showed electric conductivity mechanism corresponding to typical insulators, and irradiated in a dose range 1.8-9 d.p.a. exhibited electrical conductivity mechanism corresponding to metals. We considered the possibility to use the technique of selective changes in the atomic composition under ion beam irradiation to create the resistive elements for cryogenic temperatures. High-sensitivity superconducting SIS (superconductor-insulator-superconductor) mixers are playing an increasingly important role in the terahertz (THz) astronomical observation, which is an emerging research frontier in modern astrophysics. Superconducting SIS mixers with niobium (Nb) tunnel junctions have reached a sensitivity close to the quantum limit, but have a frequency limit about 0.7 THz (i.e., gap frequency of Nb tunnel junctions). Beyond this frequency Nb superconducting films will absorb energetic photons (i.e., energy loss) to break Cooper pairs, thereby resulting in significant degradation of the mixer performance. Therefore, it is of particular interest to develop THz superconducting SIS mixers incorporating tunnel junctions with a larger energy gap. Niobium-nitride (NbN) superconducting tunnel junctions have been long known for their large energy gap, almost double that of Nb ones. With the introduction of epitaxially grown NbN films, the fabrication technology of NbN superconducting tunnel junctions has been considerably improved in the recent years. Nevertheless, their performances are still not as good as Nb ones, and furthermore they are not yet demonstrated in real astronomical applications. Given the facts mentioned above, in this paper we systematically study the quantum mixing behaviors of NbN superconducting tunnel junctions in the THz regime and demonstrate an astronomical testing observation with a 0.5 THz superconducting SIS mixer developed with NbN tunnel junctions.

Bottom Note: *This work is partly presented at 4th International Conference on Physics*