Thin Films and Coatings

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HRTEM studies of ultrathin NbN and NbTiN films for superconducting photodetectors

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Superconducting single-photon detectors (SSPD) are novel optoelectronic devices that are currently subject of intensive research and development. The SSPDs are typically meander-type nanostructures patterned in an ultrathin superconducting NbN or NbTiN films [1].

NbN phase was the first choice material for manufacturing of SSPDs due to its stable superconducting properties at relatively high temperatures and already well established technological procedures for the ultrathin film growth and processing [2-3]. However the NbTiN phase presents advantages over the NbN phase because an addition of Ti increases metallic electrical conduction properties of NbTiN and titanium is a good nitrogen getter as well [4].

Ultrathin NbN and NbTiN films presented in this work were deposited on Al_2O_3 (0001) substrates by a high-temperature reactive magnetron sputtering method. The NbN film was deposited from Nb target in N_2/Ar gas mixture at temperature of 850°C, while the NbTiN film was deposited by co-sputtering of Nb and Ti targets. The thicknesses of the deposited films were 4 nm for NbN and 5 nm for NbTiN. Both films were annealed in Ar at 1000°C using a rapid thermal annealing (RTA) process to improve their superconducting properties.

The obtained ultrathin films were characterized by high-resolution transmission electron microscopy (HRTEM) in the JEOL JEM-2100 microscope. TEM specimens were prepared by the focusing ion beam (FIB) cross-section method in the FEI Helios NanoLab system. The DigitalMicrograph (DM) software was applied for the measurements of atomic distances using the HRTEM images of as-deposited and annealed NbN and NbTiN films.

HRTEM images (Figure 1) showed in all cases that the films fabricated on the Al_2O_3 substrate have excellent epitaxial crystalline quality. To disclosure of lattice strains distribution in the NbN and NbTiN films the atomic distances were measured across and along the cubic NbN and NbTiN films according to the rules shown in Figure 2. Results of the atomic distance measurements are presented in Table 1.

Distances in as-deposited or annealed NbN films are higher than distances in as-deposited or annealed NbTiN films. For as-deposited NbN and NbTiN samples the distances measured across the films are higher than measured along the films (i.e. in the direction along the ultrathin film-substrate interface). For the annealed NbN film the distances measured across and along the film are practically the same, in contrast to the annealed NbTiN film where the distances measured across the film are lower than those measured along the film. Observed differences between the distances for NbN and NbTiN films can be related to different lattice strains formed during deposition and their relaxations due to annealing.

HRTEM studies showed that ultrathin NbN and NbTiN films due to heteroepitaxial growth on Al_2O_3 (0001) substrate have a great compatibility and integration of these films with optoelectronic circuitry give excellent potential for their application in SSPD devices.

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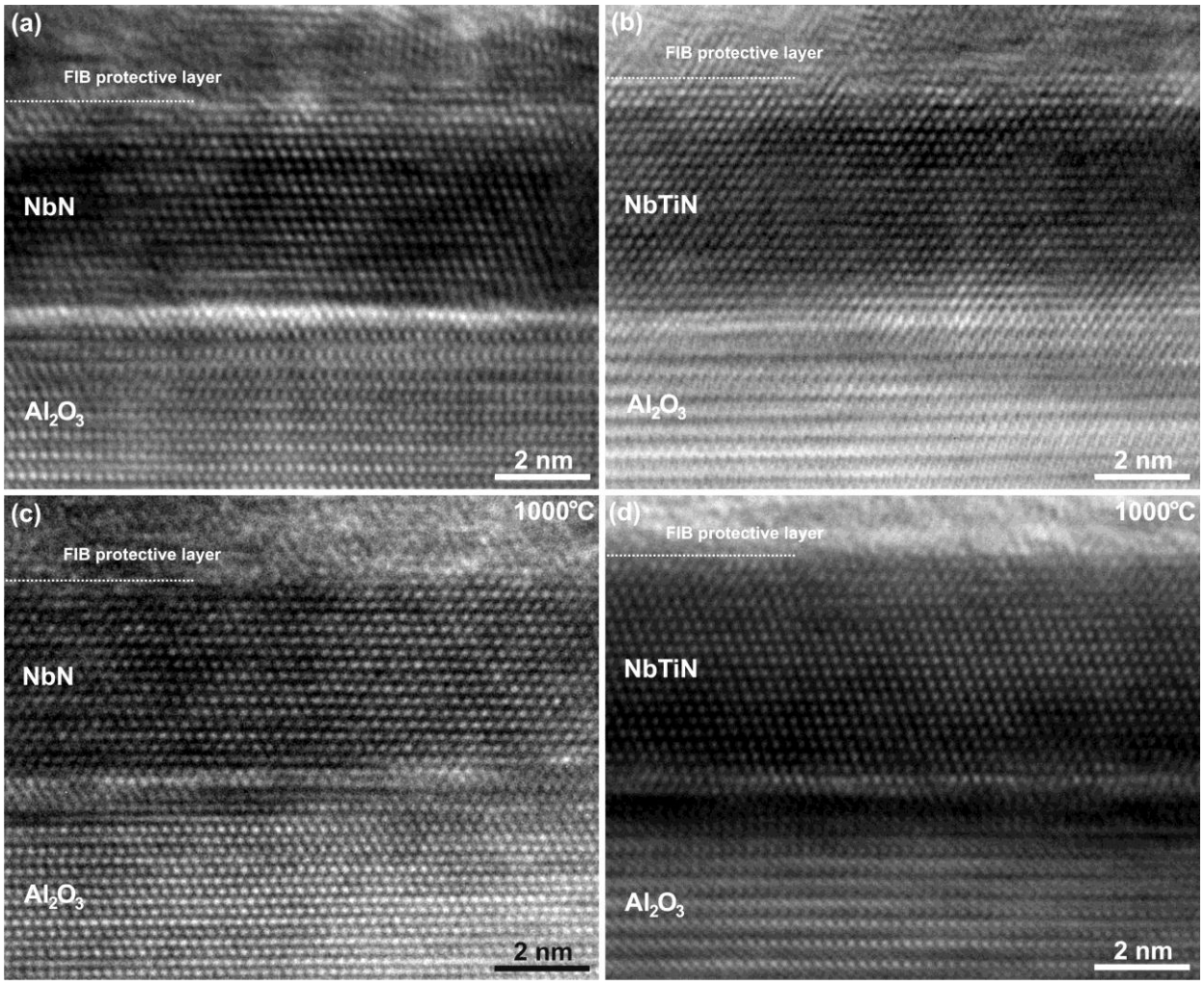

Figure 1. HRTEM images of: (a) NbN and (b) NbTiN as-deposited ultrathin films, and: (c) NbN and (d) NbTiN ultrathin films annealed at 1000°C. In all cases cubic NbN or NbTiN films were shown with (110) plane parallel to the plane of the figure.

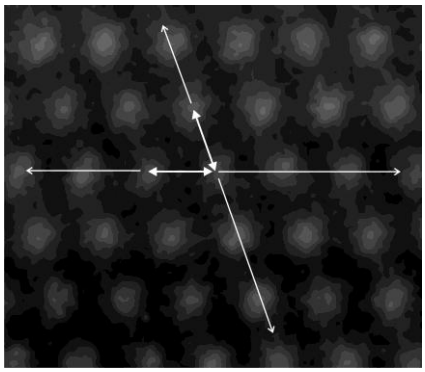

Figure 2. HRTEM image of annealed NbTiN film (high magnification fragment of Fig. 1d) with drawings related to two directions of atomic distances measurements: along (horizontal arrow) and across (inclined arrow) of the film.

sample →	as-deposited		annealed	
distance ↓	NbN	NbTiN	NbN	NbTiN
average distance measured across the film	0.2729 nm	0.2659 nm	0.2697 nm	0.2551 nm
average distance measured along the film	0.2648 nm	0.2612 nm	0.2695 nm	0.2640 nm

Table 1. Values of atomic distances for as-deposited and annealed NbN and NbTiN films. There were two directions of atomic distance measurements: across and along the films, according to the drawing shown in Figure 2. The average measured distance were calculated as a mean value of 10 distances measured across the film in 20 different places, and as a mean value of 30 distances measured along the film in 6 different places.