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ALD-BASED NbTiN STUDIES FOR SIS R&D

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Abstract

Superconductor-Insulator-Superconductor (SIS) multilayers improve the performance of SRF cavities providing magnetic screening of the bulk cavity and lower surface resistance. In this framework NbTiN mixtures stand as a potential material of interest. Atomic layer deposition (ALD) allows for uniform coating of complex geometries and enables tuning of the stoichiometry and precise thickness control in sub-nm range. In this talk, we report about NbTiN thin films deposited by plasma-enhanced ALD (PEALD) on insulating AlN buffer layer. Post-deposition rapid thermal annealing (RTA) studies with varying temperatures, annealing times, and gas atmospheres have been performed to further improve the thin film quality and the superconducting properties.

INTRODUCTION

Over the past decades, the RF performance of bulk Nb cavities has continuously improved with material and surface developments. Meanwhile we are approaching the theoretical limits of bulk niobium long-term solutions for SRF performance need to be pursued. A potential solution was proposed by A. Gurevich [1], Superconductor – Insulator – Superconductor multilayers (SIS structures). The idea is to coat the internal surface of the SRF cavities with alternating superconducting and insulating layers taking in advantage of superconductors with higher Tc than niobium. The strong increase of Hc1 in films allows to operate at RF fields higher than the Hc1 of the bulk niobium cavity since the multilayers provide magnetic screening of the bulk cavity preventing vortex penetration. Moreover, the use of higher Tc superconductors reduces the surface resistance. Therefore, the SIS structures improve the SRF cavity performance, increasing the accelerating field and reducing the losses.

In this framework NbTiN alloys stand as a potential material of interest. While NbN has a high Tc of 17.3 K, it contains a high normal conducting resistivity, which is significantly reduced with the incorporation of Ti into NbN. NbTiN alloys can be deposited by physical vapor deposition (PVD), chemical vapor deposition (CVD) and atomic layer deposition (ALD). The latter provide conformal coatings on high aspect ratio structures at low deposition temperatures, which makes it particularly interesting for coating the internal surface of SRF cavities. The deposition of NbTiN by thermal ALD, generally using chlorinated precursors [2] can introduce chlorine contamination on the deposited films while plasma-enhanced ALD (PEALD) enables metalorganic precursors, improving the quality of the deposited films.

To further improve the superconducting properties of the NbTiN films post-deposition rapid thermal annealing (RTA) has been studied.

EXPERIMENTAL DETAILS

We investigate the deposition of superconducting films of NbxTi1-xN grown on Si wafer by plasma enhanced atomic layer deposition (PEALD) using metalorganic precursors and H2/N2 plasma. The precursors used were (t-Butylimido)tris(diethylamino)niobium(V) (TBTDEN) and tetrakis(dimethylamino)titanium(IV) (TDMAT), which were maintained at 90 ºC and 70 ºC respectively. The deposition temperature was kept at 250 ºC and the plasma power at 300 W. The deposition process consists in an PEALD supercycle which alternates the PEALD cycles for the deposition of NbN (alternation of TBTDEN pulse and plasma exposure) with TiN cycles (alternation of TDMAT pulse and plasma exposure). Thus, the composition of the deposited NbxTi1-xN films can be modified varying the ratio of NbN cycles to TiN cycles run inside the ALD supercycle. Eight different Nb:Ti composition ratios were studied. As insulator the material selected was AlN since it enhances the Tc of NbTiN [3]. The precursor used was Trimethylaluminum (TMA) and was kept at room temperature. Both layers, AlN and NbTiN were deposited within the same PEALD process on Si wafer.

After the deposition, the NbTiN films were annealed at 800, 900 and 1000 ºC varying the annealing duration between 5 and 50 min. The heating rate was 1 ºC/s. Different gas atmospheres (Ar/H2 and N2/ H2 mixtures, pure N2 and pure H2) were studied.

RESULTS

Superconducting properties have been studied as a function of the ratio of Nb to Ti content present in the films. The films composition was analysed using EDX. The Nb:Ti composition ratio measured matches with the ratio of NbN to TiN within the PEALD supercycle, enabling efficient tuning of film composition (see Fig. 1).

Post-deposition rapid thermal annealing (RTA) varying temperature, annealing time and gas atmospheres have been performed in order to study the influence of these parameters on the superconducting properties. Higher annealing temperatures show a larger increase of Tc. The effect of the annealing duration varies depending on the annealing gas atmosphere and needs to be studied more in detail. After 1000 ºC RTA, Tc increased from 6.25 K to 14.3 K for 25 nm Nb0.75Ti0.25N films. The residual resistance decreases after RTA and no cracks were found in the films (see Fig. 2).

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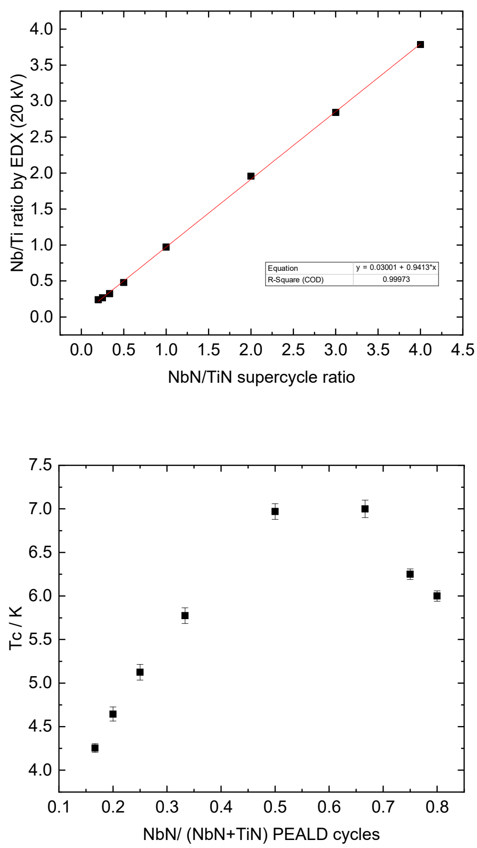

Figure 1: Linear relationship between the ratio of Nb to Ti concentration measured by EDX and the NbN to TiN ratio within the supercycle of PEALD (top) and variation of the critical temperature for the different ratios of NbN to TiN supercycles during the PEALD process (bottom).

CONCLUSIONS

Superconducting NbTiN alloys have been synthesized by PEALD and the effect on the Tc of their composition has been studied. Post-deposition annealing has been found to be mandatory in order to significantly improve the Tc of the deposited NbTiN films. Further analyses are needed to understand the observed improvement. A maximum critical temperature of 14.3 K has been reached for 25 nm thick of $Nb_{0.75}Ti_{0.25}N$ film after RTA at 1000 ºC.

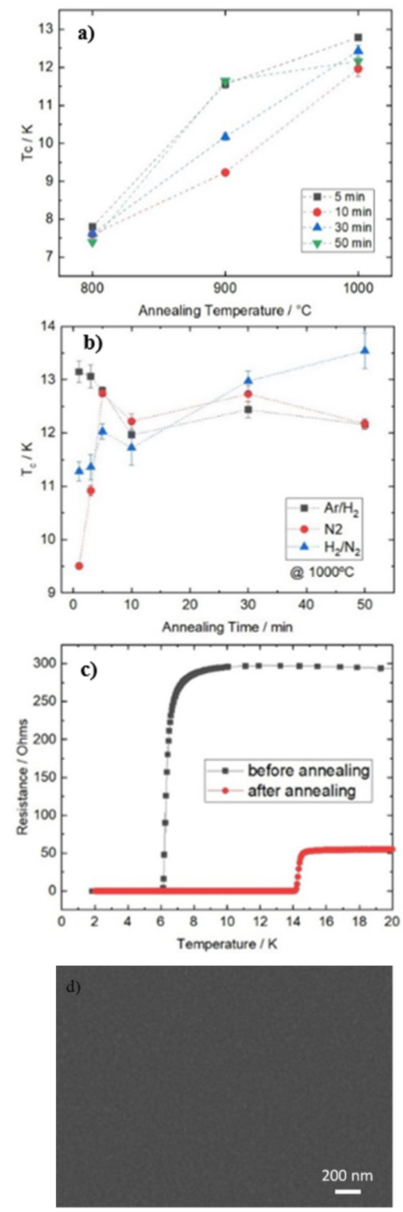

Figure 2: Effect of the post-deposition rapid thermal annealing on NbTiN film. a) Tc vs annealing temperature for different annealing times. b) Tc vs annealing time for gas atmospheres. c) Resistance vs temperature curve for NbTiN film before and after the RTA. d) SEM image of an AlN / NbTiN multilayer deposited on Si wafer by PEALD. No cracks were observed after thermal annealing.

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