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TOPOGRAPHY AND ELECTRICAL PROPERTIES OF SPUTTERED NIOBIUM FILMS

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Abstract:

For the improvement of the properties of Nb films in view of a possible application in TESLA-type resonators, knowledge about the connection of film structure/topography and electrical properties is necessary. Therefore, Nb films from different sites of a 1.5 GHz resonator were investigated and compared with results of usual planar deposition. The present results give information on topography and electrical properties of this Nb films. The films were deposited on quartz substrates in the resonator and on various substrates by planar dc magnetron deposition. The topography of the films was examined by scanning electron microscopy (SEM) and by atomic force microscopy (AFM). The residual resistance ratio (RRR) and critical temperature (Tc) were measured.

Keywords: niobium films, topography, superconductivity

1. Introduction

Nb sputter coated Cu resonators are a possible approach for mass production of superconducting resonators for the new generation of colliders. Recent studies at CERN [6] on sputtered Nb films onto spun seamless Cu 1.5 Ghz resonators indicate that the traditional Q-degradation versus accelerating field can be overcome. Therefore Nb films must be investigated intensively [1-4].

In the present paper we give information on topography and electrical properties of Nb films on quartz substrates in dependence on the position in the resonator during the deposition. In particular, samples from the high magnetic field region (resonator equator) and from the high electric field region (resonator tube) were investigated. Large microstructural differences were found. We also investigated samples deposited by a planar balanced magnetron deposition.

It was found that Nb films with elongated grains show the best RRR values. We suggest that this grain shape is caused by a large plasma particles bombardment during deposition.

2. Experimental

At three characteristic places in a 1.5 GHz cavity (equator, tube and transition region) quartz substrates of $1x1cm^2$ were fixed and coated by cylindrical magnetron sputtering, by means of the dc post magnetron configuration, [fig 1] described in detail elsewhere [9].

The necessary magnetic field was produced by external coils separated by a gap at the cell level; the deposition parameters were: Residual pressure of $5\ 10^{-9}$ mbar, argon pressure during sputtering of $3\ 10^{-2}$ mbar, sputtering power of 4 kW and a target-substrate-distance (TSD) in the range of 2,3 cm (tube region) to 7,3 cm (equator region). Corresponding to TSD the deposition rate was in the range of few nm/s.

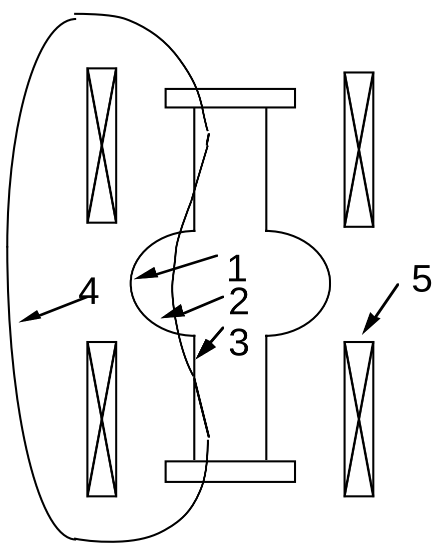

Fig. 1: Magnetic configuration of the cylindrical sputtering system.

1) equator,
2) intermediate region,
3) iris,
4) magnetic field line,
5) coil

On the other hand Nb films were prepared by planar balanced dc magnetron sputtering on different substrates (oxidized Silicon wafer, glass and polished copper), in a usual high vacuum equipment. The deposition parameters were: residual pressure with liquid N_2 baffle of $4\ 10^{-7}$ mbar, argon pressure during sputtering of $6\ 10^{-3}$ mbar, sputtering power of 360 W and a TSD of 6 cm. The deposition rate was 1.5 nm/s

The film thickness was determined with a profilemeter. The electrical resistance was measured with a 4-wire-connection. The topography of the films was investigated by scannig electron microscopy (SEM DSM 962 of Zeiss) and by atomic force microscopy (AFM Explorer of TopoMetrix).

3. Results

The topographies of the Nb films are represented versus the position in the resonator in fig.2. Characteristic structural differences are visible. Whereas in the equator region the topography reflects a typical columnar grain growth with a grain size of about 300 nm, in the tube region it shows clearly larger and elongated grains.

In table 1 the corresponding results of film thickness t_{Nb}, residual resistance ratio (RRR) critical temperature T_c and the average grain diameter are given. These values confirm that the RRR value and the Nb grain size are increased with the increased film thickness, corresponding to [1, 3]. The very large RRR value of 100 for the Nb film of the tube region with elongated grains is remarkable. The Tc values are nearly independent of the film thickness and larger than for bulk material. These larger Tc values are typical for pure and stressed Nb films [4].

position	t_{Nb} [µm]	RRR	T. [K].	grain diameter [nm].
equator	2.5	28	9.51	300
intermediate	4	50	9.5	500
iris	8	100	9.49	elongated grains 1µm long

Table 1: Film thickness tNb, residual resistance ratio (RRR), critical temperature Tc and grain diameter of the Nb films on quarz substrates in dependence on the position in a 1.5GHz resonator

The topography of Nb films deposited by planar dc magnetron sputtering on various substrates is shown in fig. 3. The grain size increases with increasing film thickness. Due to lower sputtering pressure of $6 \cdot 10^{-3}$ compared to $3 \cdot 10^{-2}$ mbar of the resonator deposition, the grain size is smaller, corresponding to [5]. Indipendently of the film thickness and the substrate material, the grain shape is similar to the elongated grains from the resonator tube region.

For both cases it is suggested that the elongated grain shape is due to a larger plasma particles bombardment during deposition.

The microstructure of sputtered films is affected by several factors; among them energetic particle bombardment [7], and angle between incident sputtered flux and substrate [8].

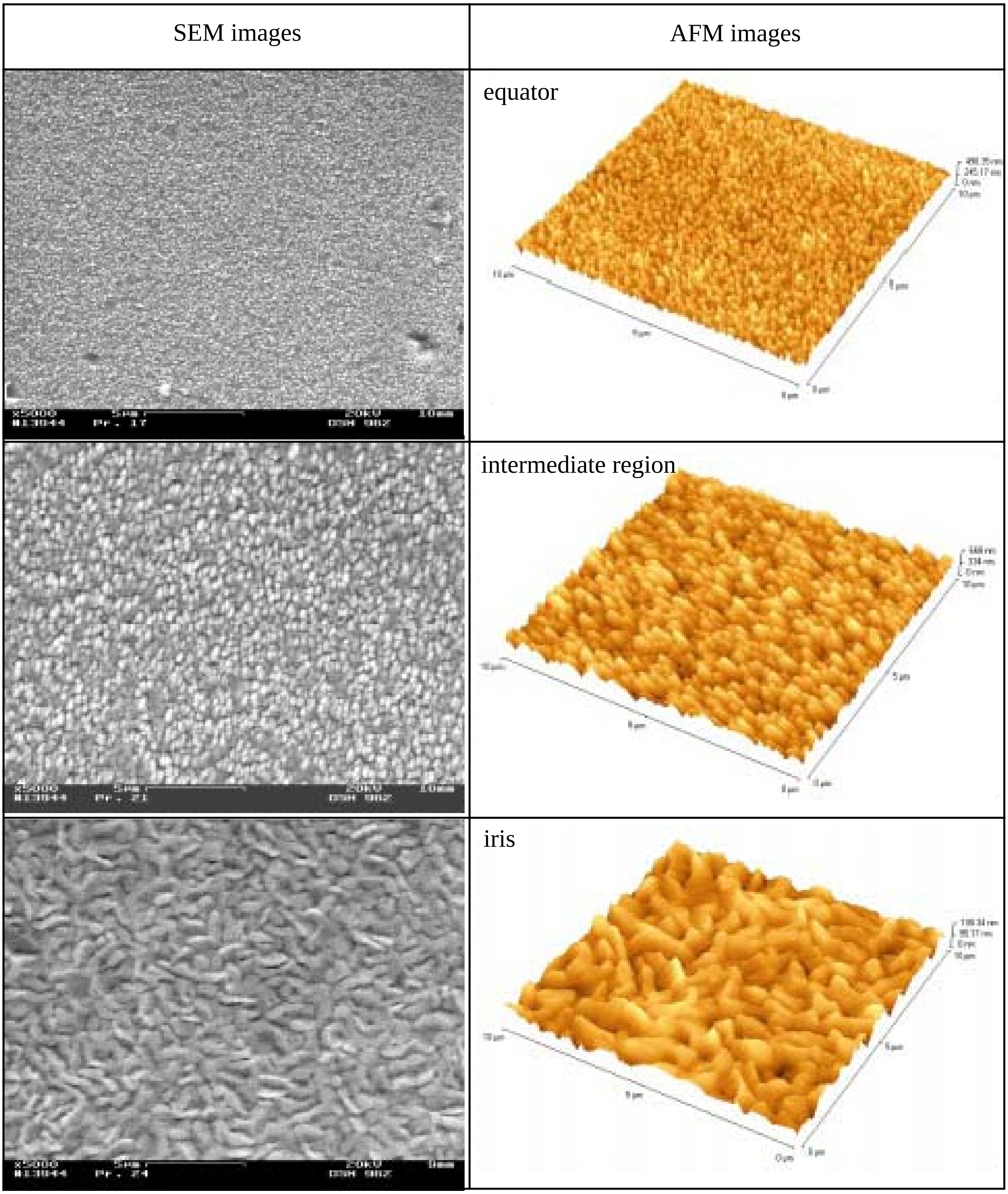

Fig. 2: SEM and AFM images of the Nb films on quartz substrates in dependence on the position in the 1.5 GHz resonator: equator, intermediate and iris regions

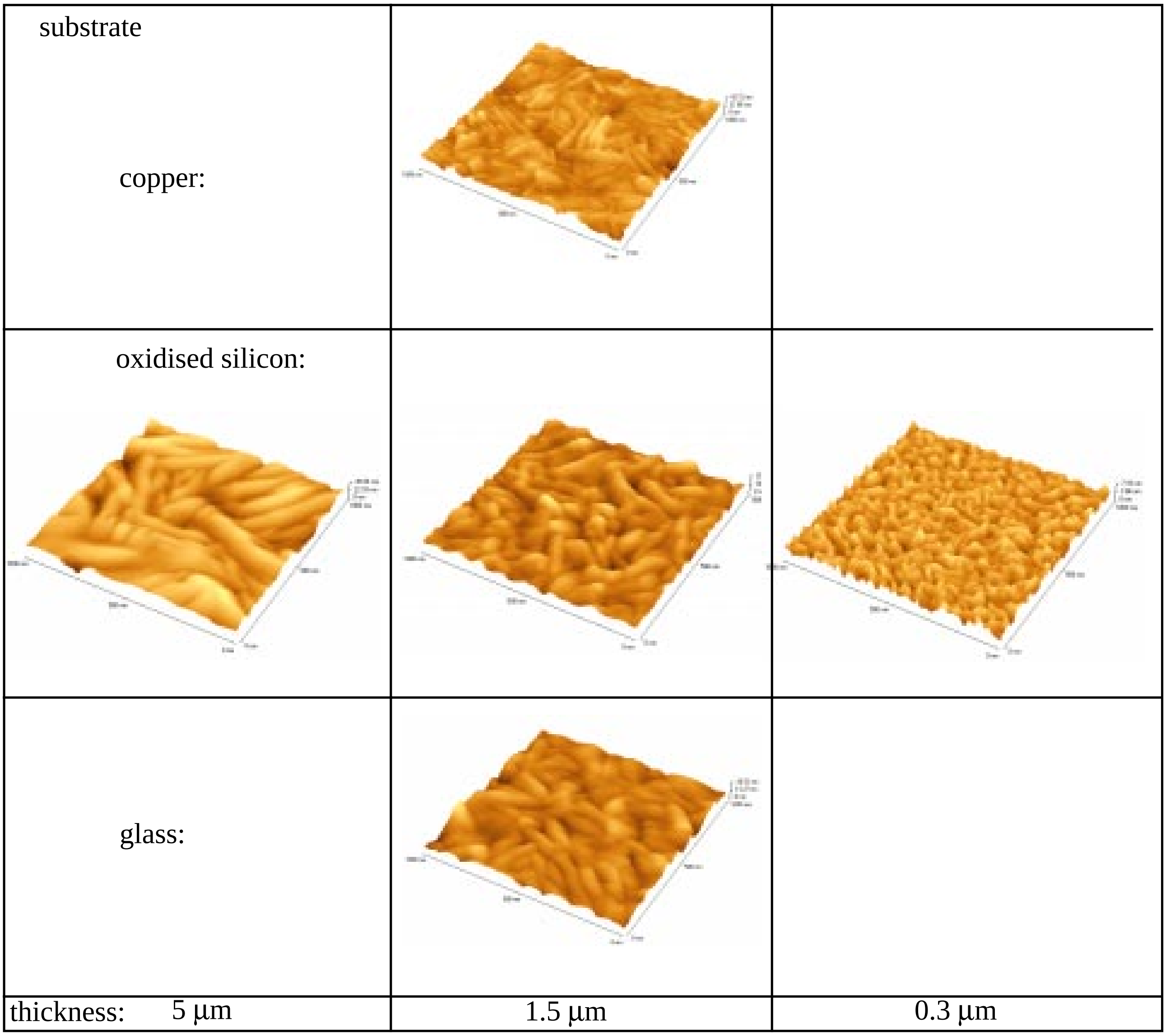

Fig. 3: AFM images of Nb films on different substrates and for several film thicknesses deposited by planar dc magnetron sputtering, each image: $1\mu m^2$

In table 2 the residual resistance ratio (RRR) and critical temperature Tc for this Nb films on oxidized silicon substrates in dependence on the film thickness t_{Nb} are shown.

The RRR value and the Nb grain size are increased with increasing film thickness. The largest

film thickness [µm]	RRR	Tc [K]
0.2	2.0	7.9
0.5	2.8	8.6
1.5	7.7	9.24
5.0	10.7	9.28

Table 2: Residual resistence ratio (RRR) and critical temperature Tc for Nb films deposited by planar sputtering on oxidized silicon substrate in dependence on film thickness tNb

Tc is close to the bulk value. However, in opposite to the resonator films the Tc values for the same thickness are smaller, possibly caused by a larger residual pressure in the deposition equipment.

4. Conclusion

Nb films deposited by cylindrical deposition in a resonator show characteristic differences in thickness, RRR, grain size and shape in dependence on the position: equator, transition and iris region.

Pure and thick Nb films with elongated grain shapes, deposited in the tube region of the resonator, show the largest RRR value.

Nb films deposited by planar deposition with different thicknesses and on several substrate materials show also a elongated shape of the Nb grains.

It is suggested that the elongated Nb grain shape is caused by a large energetic particle bombardment during the sputter deposition.

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