

FORMATION A RIBBON SUPERCONDUCTOR ON A NIOBIUM NITRIDE MATRIX BY ION PLASMA SPUTTERING

A. Zh. Tuleushev, Yu. Zh. Tuleushev, V. N. Lisitsyn, V. V. Volodin and S.N. Kim

Institute of Nuclear Physics – Kazakhstan National Nuclear Center

Despite the enormous efforts of researchers and developers, turned to improvements in the field of high-temperature superconductivity, the helium superconductors created earlier are, still, are the top-technology elements in strong-current devices, including the coils used for creation of magnetic fields. At present in industries, the diffusion-technology wire superconductors with a core made of Nb_3Sn or $NbTi$ are widely used. The costs for the products made following this way are higher by three orders of magnitude than those of raw materials, witnessing that expenditures for production are high. One of the general disadvantages of the technology is impossibility of forecasting the product quality till a ready product is produced, because one can't determine an amount of the strings damaged under mechanical treatment. In addition to technological problems, the wire superconductors suffer from a serious irrevocable disadvantage: presence of transverse currents in a conducting matrix under magnetic dynamics, effecting negatively on superconductivity. The design of a superconductor representing a thin film on a ribbon made of the metal - good heat-conductor is free of this disadvantage. One of the ways for deposition of a superconducting coating is the ion plasma technology where synthesis of a required substance is combined with transport of primary components from a target to a product.

This technology involves a small number of operations, being the most efficient. The major tasks to be performed in the course of development of the film technology include the efficiency of a sputtering system and the regime that provides a required phase of an obtained superconducting coating. Solution of these problems is exemplified by production of ribbon superconductors coated by delta-niobium nitride, realised in our institute.

The technological process has been developed, as applied to the planar direct-current magnetron sputtering systems (MSS) characterised by a high rate of sputtering the target materials, created to the beginning of the studies, with the outcomes of preliminary developments concerning synthesis of the coatings deposited onto the niobium nitride substrate taken into account. Challenge of the MSS is caused by higher temperatures of transition from the $\delta_I(NbN)$ phase to superconductivity at these conditions.

As a prototype of equipment, the original technological line, we developed for deposition of coatings from noble metals, is operated at present at the Kazakhstan National Monetary Yard. In view of the proper facility operation, we have developed the system for preparation and sup

ply of a plasma-generating gas, composed of an argon-nitrogen mixture, and the system for movement of a ribbon backing. In the latter, the ribbon backing is disposed on a roller bed over periphery of a rotating platform opposite to the magnetrons. Rotation of the platform provides repeated intersection of plasma fluxes by each segment of the ribbon, and, as a result of each intersection, a sub-layer is deposited, resulting in formation of a coating as a whole. Formation of the coating of a specified thickness from a large number of thinnest layers (several nanometers) turned out important for homogeneity of the phase composition. At the same time, a ribbon is carried from one drum to another; both disposed at the platform common to the driving device. The latter circumstance provides identity of formation conditions for every ribbon part. The film superconductor coating 1 to 1.5 micron thick on the ribbon having the width up to 50 mm and the length more than 30 is produced at the rate of movement comprising 0.8 to 1.2 m/hour.

The thickness of the layers niobium nitride, as well as titanium and titanium nitride as the coating components is determined by the technique of the Rutherford backscattering at the charge exchange accelerator UKP-2-1.

When producing a ribbon with a superconducting coating, we have to overcome a number of technical difficulties caused by crack formation in a coating, when a layer of niobium nitride is deposited directly onto a copper ribbon, due to differences in the coefficients of linear expansion. As a backing, the copper ribbon of the thickness 15 to 20 μm is used. The ribbon provides heat removal as the conductor returns to normal conductivity. With respect to the ribbon, as an optimum intermediate layer, the composition was determined, consisting of the layers of titanium and titanium nitride, which provides subsequent transition from the copper FCC lattice having the period 3.615 Å to the cubic lattice of titanium with the period 3.307 Å, then to the *TiN* FCC lattice with the period 4.240 Å FCC lattice with the period and the *NbN* FCC lattice with the period 4.386 to 4.396 Å and a high level of coating adhesion relatively to non-headed substrate, being important for a multi-layer structure. A specified thickness of layers, in combination with good conductivities of titanium and titanium nitride, provide rather high strength and critical¹ characteristics of the conductor.

Another solved problem is related to absence of regular cubic lattice for delta-niobium nitride when is directly synthesised in the plasma chamber; formation of a lattice depends of the nitrogen content in a gas mixture (Table 1)

¹ The latter is proved by cryogenic trials.

Table 1 - The lattice parameter of the $\delta_1(\text{NbN})$ phase versus the nitrogen concentration in a gas mixture

The nitrogen concentration, vol. %	d_{111} , nm	d_{200} , nm	d_{220} , nm	a_1 , nm	a_2 , nm	a_3 , nm
39	0.2543	0.2168	0.1501	0.4404	0.4336	0.4246
36	0.2574	0.2202		0.4458	0.4404	
33	0.2568	0.2196	0.1551	0.4448	0.4393	0.4380
30	0.2574	0.2196	0.1571	0.4458	0.4392	0.4443
27	0.2550	0.2201	0.1561	0.4417	0.4402	0.4415
25	0.2539	0.2201	0.1555	0.4398	0.4402	0.4397
23	0.2536	0.2198	0.1555	0.4392	0.4396	0.4398
22	0.2536	0.2198	0.1556	0.4392	0.4396	0.4440

A spread in the lattice parameter values for niobium nitride was eliminated after thermal treatment in vacuum at 700 to 740°C. Influence of the annealing temperature can be observed at a sample (Table 2) obtained in the course of niobium nitride synthesis in the gaseous medium containing 39% of nitrogen. Thus, one can govern the parameters of the crystalline lattice of niobium nitride, which, in turn, is responsible for the critical temperature of transition to a superconductivity state, varying the nitrogen content in the gas phase and applying subsequent vacuum thermal treatment.

Table 2 – Influence of annealing on parameters of the crystalline lattice of a *NbN* sample

$T_{\text{annealing}}$ (°C)	The annealing duration (hour)	d_{111} , nm	d_{200} , nm	d_{220} , nm	a_1 , nm	a_2 , nm	a_3 , nm
390	1	0.2543	0.2168	0.1501	0.4404	0.4336	0.4246
500	1	0.2536	0.2168	0.1532	0.4392	0.4336	0.4333
740	1	0.2515	0.2179	0.1541	0.4356	0.4358	0.4359

The stated above is illustrated by figure 1.

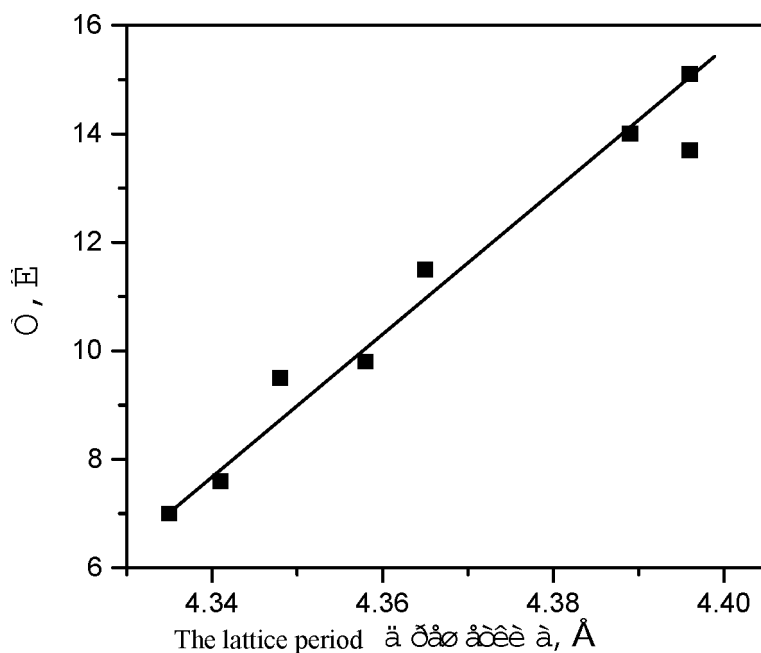


Fig.1. The transition critical temperature versus the lattice period for niobium nitride

As a result of the performed technical studies, we have managed to reach, under optimal technological parameters, steady reproducibility of ribbon superconductors on the delta-niobium backing with the transition critical temperature about 15 K with the values of the lattice parameter 4.4Å. and the critical current $50000 \text{ A}\cdot\text{cm}^{-2}$

As a result of the studies, it has been found that production of delta-niobium nitride of stoichiometric composition is governed by the nitrogen content in a gas phase, the amount of sputtered niobium and the cluster energy state, determined, in turn, by the power supplied to a magnetron, the pressure within a synthesis band, the substrate disposition and the motion relatively a plasma flux and by other factors.

The developed technology for production of a ribbon superconductor on a niobium nitride substrate involves operations of the preliminary and finishing treatment of a ribbon surface, subsequent deposition of coatings of titanium or titanium nitride and formation of the proper superconducting niobium nitride coating with/without subsequent thermal treatment. Deposition of the layers of titanium nitride, titanium and copper over the superconducting phase is possible as well as repetition of the combinations.

Thus, the studies we performed show that the ion plasma technology for production of ribbon superconductors is quite fitted to industrial applications.