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Progress with the Deposition of Niobium Nitride Thin Films on Copper

S. Leith*, M. Vogel, X. Jiang, Universität Siegen, Germany
E. Seiler, R. Ries, IEE SAS, Bratislava, Slovakia

Introduction

NbN thin films have been the subject of considerable research since the 1980's, firstly to be utilised in Josephson junctions or more recently, as part of multilayer coatings for superconducting radio frequency (SRF) cavities. So far their deposition has been limited to commercially available substrates such as Si and MgO, or Nb.
In this contribution, results from a screening study probing the effects of various deposition parameters on the resulting film microstructure, phase formation and subsequent superconducting properties of NbN thin films deposited onto copper are presented.
The resulting films were characterised using, among others, scanning electron microscopy (SEM), x-ray diffraction (XRD) and a DC magnetisation setup. Initial results indicate a large variance in the microstructure and phase formation which result in changing superconducting properties

Experimental

NbN thin films were deposited using DC reactive magnetron sputtering using a Nb (RRR 300) target in the presence of a mixture of argon (99.998 Vol-%) or krypton (99.999 Vol-%) and nitrogen (99.999 Vol-%). The Ar/N_2 ratio was maintained via flow rate control of the two gases.

Table 1: High and low values of chosen deposition parameters

Parameter boundary	Substrate Temp [°C]	Pressure [mPa]	Bias [V]	N_2 content [%]	Gas	Cathode Power [W]
high (+)	600	1600	-80	30	Ar	500
low (-)	200	800	0	10	Kr	300

Results and Discussion

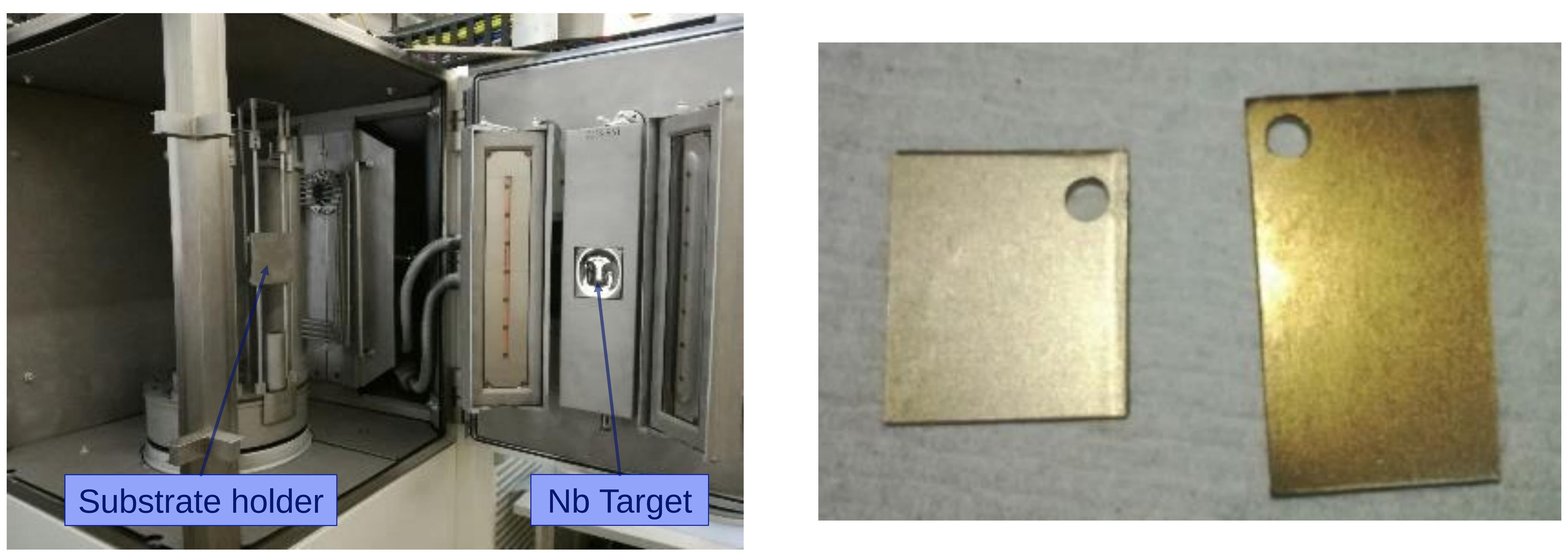

Figure 1: (Left) Commercial CemeCon CC800 coating tool (Deposition Chamber) (Right) Optical image of two separate NbN thin films, showing different resultant film colour

SEM investigations reveal the following:

- For a dense film, a high substrate temperature is preferred, but not mandatory, provided that a substrate bias and high cathode power is applied, as indicated in Figure 2a
- High pressure tends to grow porous and highly disconnected columnar films, while low pressure deposition leads to dense films and adherent columns, as shown in Figure 2b
- A low cathode power can be compensated for by applying a substrate bias, provided that there is a high enough mean-free-path (low pressure)
- The substitution of Ar with Kr as working gas, and the variation in N_2 % does not seem to change the growth modes significantly within this parameter window

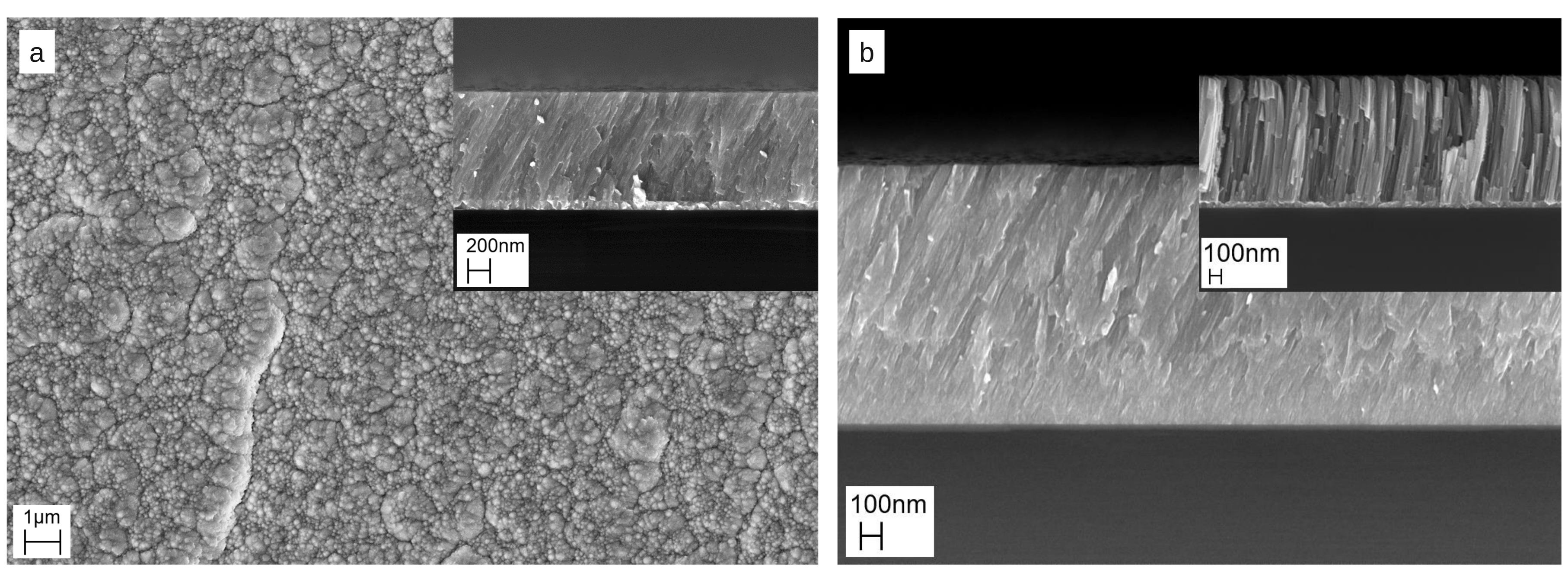

Figure 2: (a) (Main) Plain view of dense NbN film. (Inset) cross section view of the same film. (b) (Main) Low pressure dense and adherent film. (Inset) High pressure porous columnar growth

Surface roughness varies with deposition parameters

- Effects more apparent with AFM scans (5 x 5 µm) than CLSM scans (257 x 257 µm)
- Indicates more of an influence on microstructure, e.g. grain morphology

Table 2: Deposition parameter effects on the surface roughness of NbN thin films

Parameter boundary	Substrate Temp [°C]	Pressure [mPa]	Substrate Bias [V]	N_2 content [%]	Process Gas	Cathode Power [W]
High	Equal	-	+	-	+	+
Low	Equal	+	-	+	-	-

Table 3: Elemental composition of NbN thin films deposited with differing N_2 flow rates

N_2 flow %	Nb (at.%)	N (at.%)	O (at.%)	x
10	48.8	46.2	5	0.95
15	48.75	45.17	6.07	0.93
20	48.30	45.75	6	0.95
25	45.71	51.37	2.90	1.12
30	48.70	50.86	0.43	1.04

RBS analysis revealed the following:

- Nb:N ratio places films in band for δ, ϵ and δ′ - NbN phases
- Absence of the β-NbN and γ-NbN phases, x = 0.4 to 0.8, for these parameters
- Decrease in oxygen content with an increase in N_2 flow

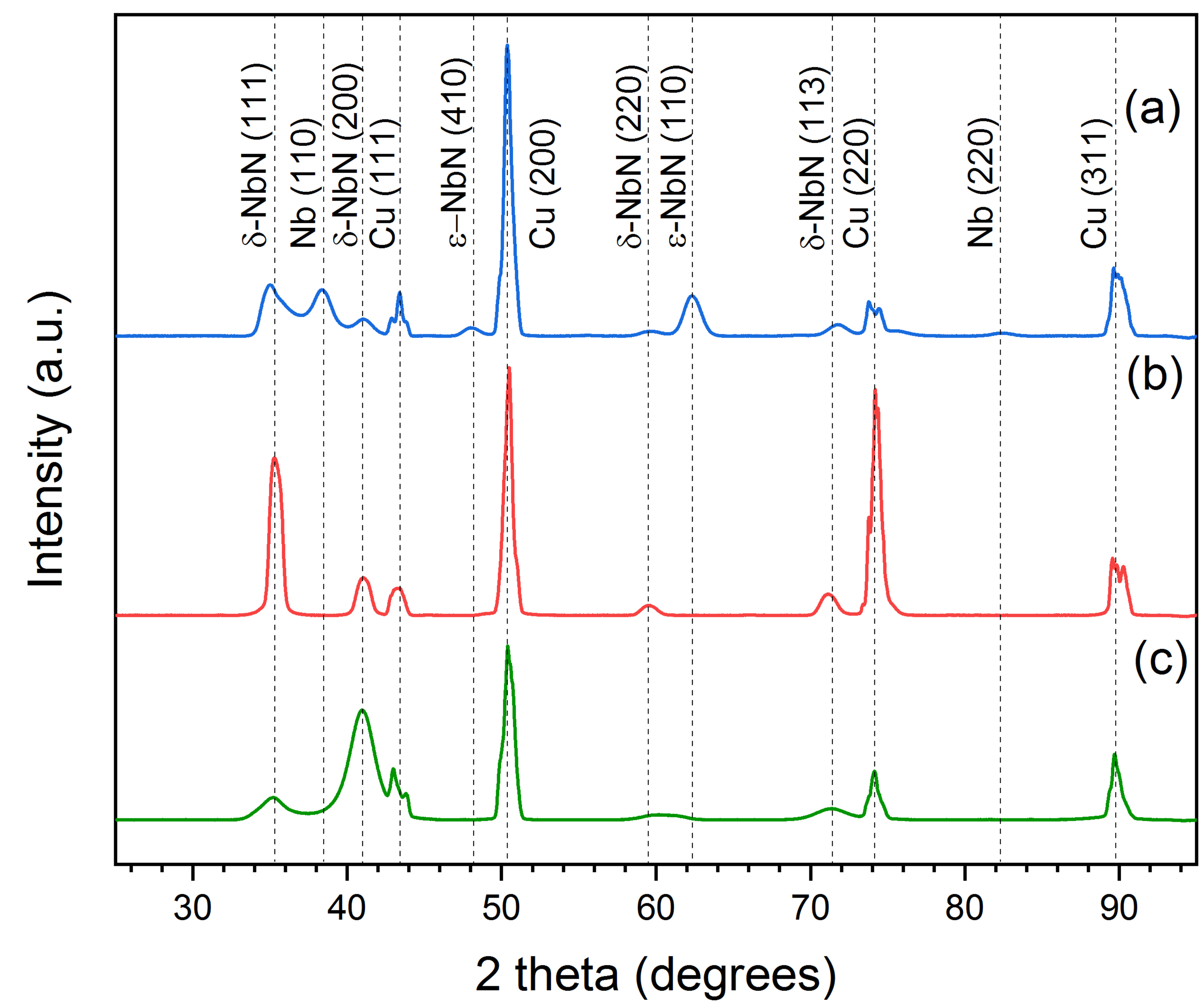

Figure 3: Representative XRD scans for samples with various phases and superconducting properties

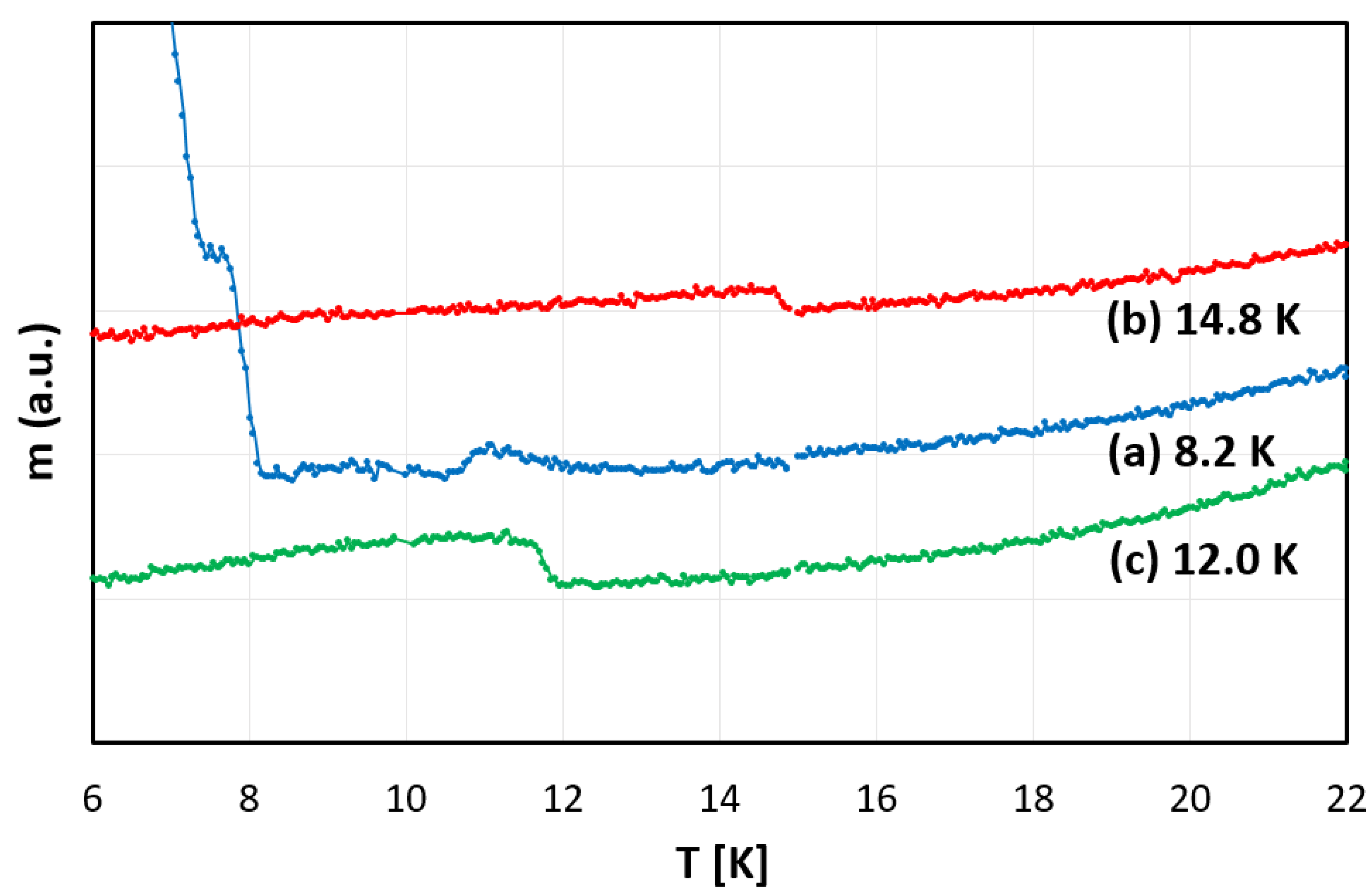

Figure 4: T_C measurements of NbN/Cu thin film samples using a Vibrating Sample Magnetometer (VSM)

Conclusions

- A high temperature, low pressure and high cathode power lead to dense and adherent film growth
- Use of Kr results in lower surface roughness compared to Ar at lower length scales
- Lower nitrogen flows (10 %) leads to superior superconducting performance with higher likelihood of δ - NbN formation, but higher oxygen content
- Improvement possible with smoother substrate surface

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Contact

Stewart Leith
stewart.leith@uni-siegen.de
Tel: +49 271 740 2145