# HiPIMS NbN Thin Film Development for use in Multilayer SIS films

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## Introduction

As part of efforts to improve the performance of SRF cavities, the use of alternative structures, such as SIS film coatings have been extensively investigated. Initial efforts using DC MS deposited NbN films showed the efficacy of this approach [1]. The use of energetic condensation methods, such as HiPIMS, have already improved the performance of Nb thin films for SRF cavities and have already been used for nitride film coatings in the tool industry.
In this contribution, the results from the deposition of HiPIMS NbN thin films onto OFHC Cu substrates are presented. The HiPIMS parameters were kept constant at 1000 Hz and 120 µs for all coatings, in conjunction with a constant DC substrate bias. A gas mixture of argon and nitrogen was used for all coatings, with the gas ratio maintained by flow rate control. The effects of the different deposition parameters, which are presented in Table 1, on the deposited films were elucidated through various characterisation methods, resulting in an optimum coating procedure. This allowed for further comparison between the HiPIMS NbN films and the previously presented DC MS NbN films.

**Table 1:** Set point ranges for the varied deposition parameters used for the NbN film coatings

| Parameter boundary | Cathode Power (average) (W) | Deposition Pressure (mbar) | Substrate Bias (V) | $N_2$ content (%) |
|---|---|---|---|---|
| **High** | 600 | $2.4\times10^{-2}$ | 100 | 22 |
| **Low** | 300 | $1.2\times10^{-2}$ | 0 | 5 |

## Morphological and Topographical Results

- Low pressure deposition results in a nanocrystalline grain structure. Increased deposition pressure leads to columnar growth and more faceted grain peaks, resulting in a higher surface roughness.
- Increasing substrate bias markedly improves the film density and rounds the grain peak as seen in fig 1. (a) 0 V and (c) 100 V.
- Increased $N_2$% leads to improved film density and rounder grain peaks, as shown in fig1. (b) 5 % and (d) 22 %. This leads to a lower surface roughness.
- Films deposited at lower cathode powers show consistently rougher surfaces.
- The surface roughness evolution is consequently linked to the NbN phase formation.

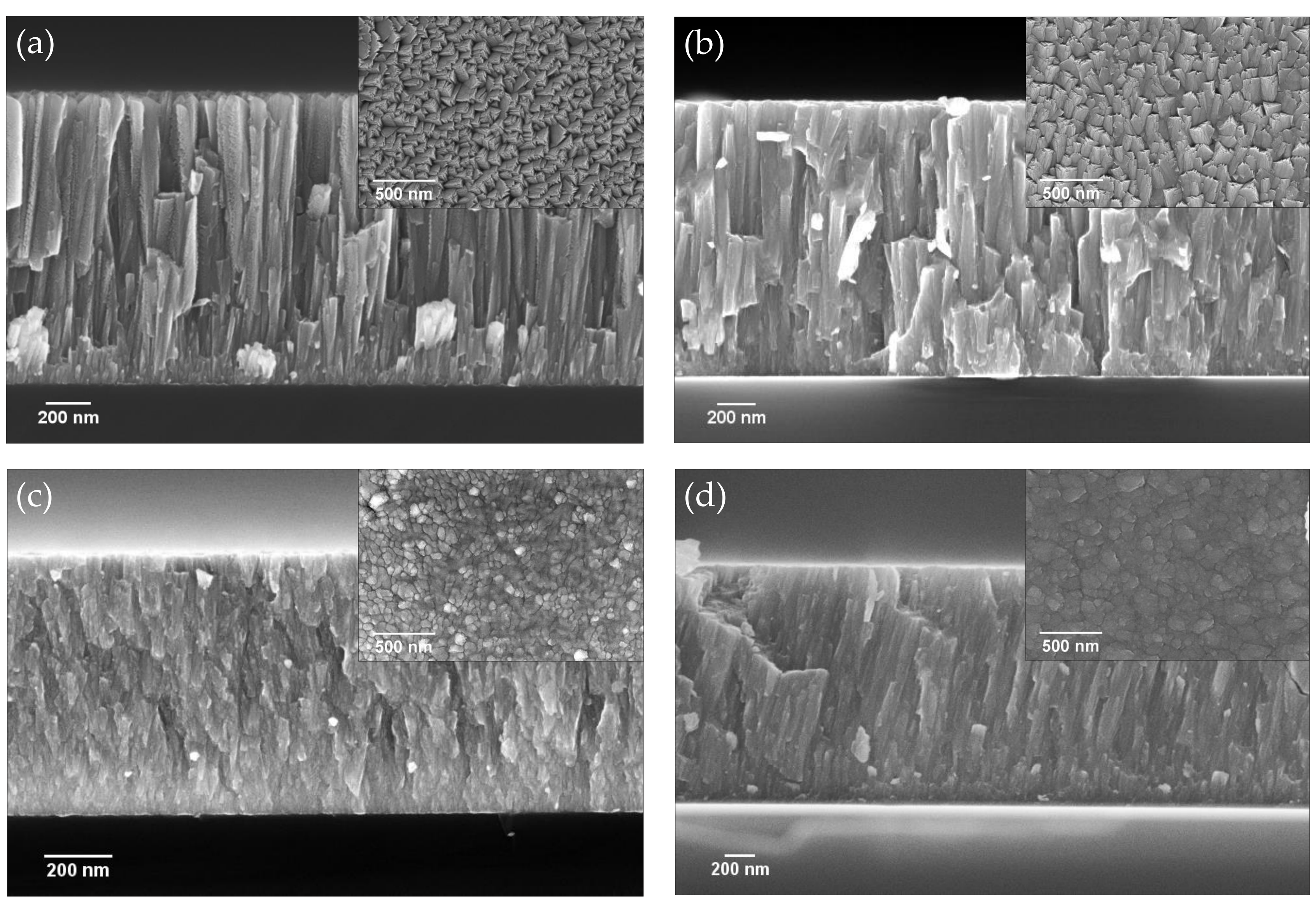


**Figure 1:** SEM images of samples deposited with 400 W cathode power and $2.2\times10^{-2}$ mbar deposition pressure with different substrate bias and $N_2$ %. (a) and (c) denote the cross-section on Si and the surface on Cu of films deposited with 0 and 100 V substrate bias respectively. (b) and (d) denote the same for films deposited with $N_2$ % values of 5 and 22 % respectively.

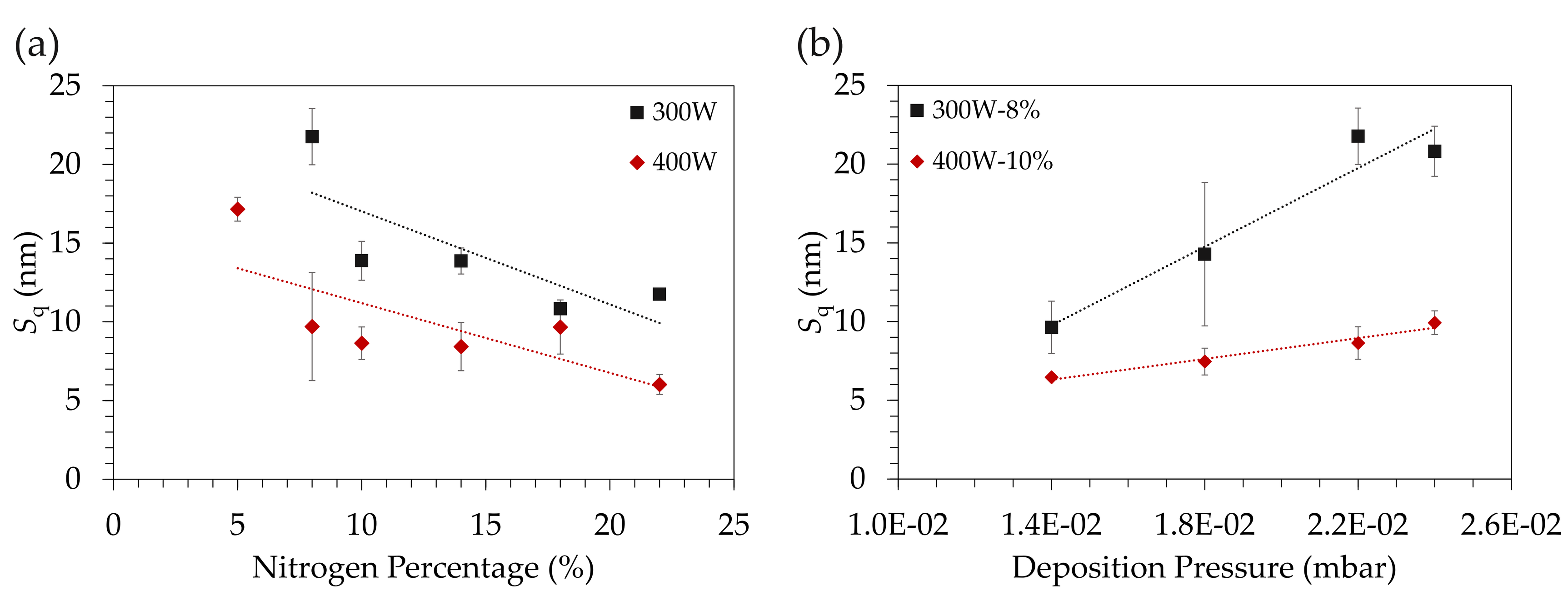


**Figure 2:** Average RMS surface roughness results of NbN films deposited onto Cu, as determined with three 5 x 5µm AFM measurements per sample. (a) The change in surface roughness as a function of $N_2$ %. (b) The change in surface roughness as a function of deposition pressure.

## Crystallographic Results

- Low deposition pressure results in formation of non-superconducting hexagonal phases.
- Improved formation of δ-NbN (111) phase at lower cathode power values. No spurious phases. Films transition from δ-NbN (111) to δ-NbN (200) with increasing $N_2$%.
- Lattice parameter values match bulk δ-NbN at intermediate bias levels. Loss of δ-NbN phase at high substrate bias levels (> 60 V).

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## Crystallographic Results Cont.

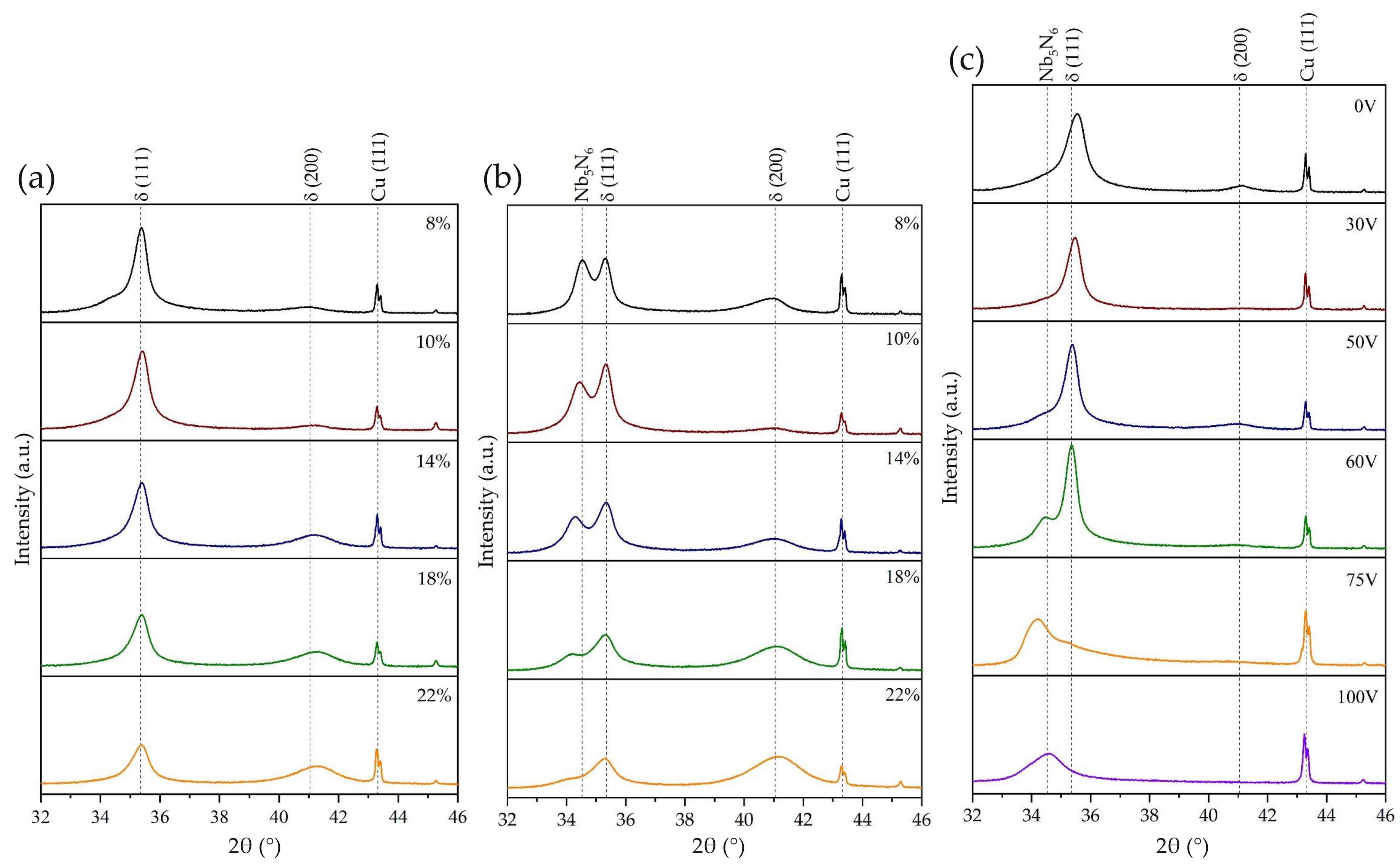


**Figure 3:** XRD patterns of samples deposited at (a) 300W and (b) 400W with different $N_2$ % values. (c) Samples deposited at 300W, 8% $N_2$ and increasing substrate bias values. The samples were deposited at a constant deposition pressure of $2.2\times10^{-2}$ mbar. The spectra are plotted in log scale.

## Superconducting Results

- Highest $T_c$ = 16.5 K achieved with HiPIMS compared to 16.1 K for DC MS [1]. Decreasing $T_c$ trend with increasing $N_2$%. Increasing $T_c$ trend with increasing pressure.
- Specific maximum in $H_{en}$ between 10 to 15 % $N_2$. Improved $H_{en}$ for higher relative average cathode power. Significant improvement in $H_{en}$ (Max) of HiPIMS NbN vs. DC MS NbN (30.0 mT vs. 13.0 mT). HiPIMS NbN $H_{en}$ > bulk NbN $H_{c1}$ (20.0 mT) [2]
- Significant decrease in $T_c$ and $H_{en}$ at substrate bias > 60 V. Complete loss of superconductivity at 100 V substrate bias.

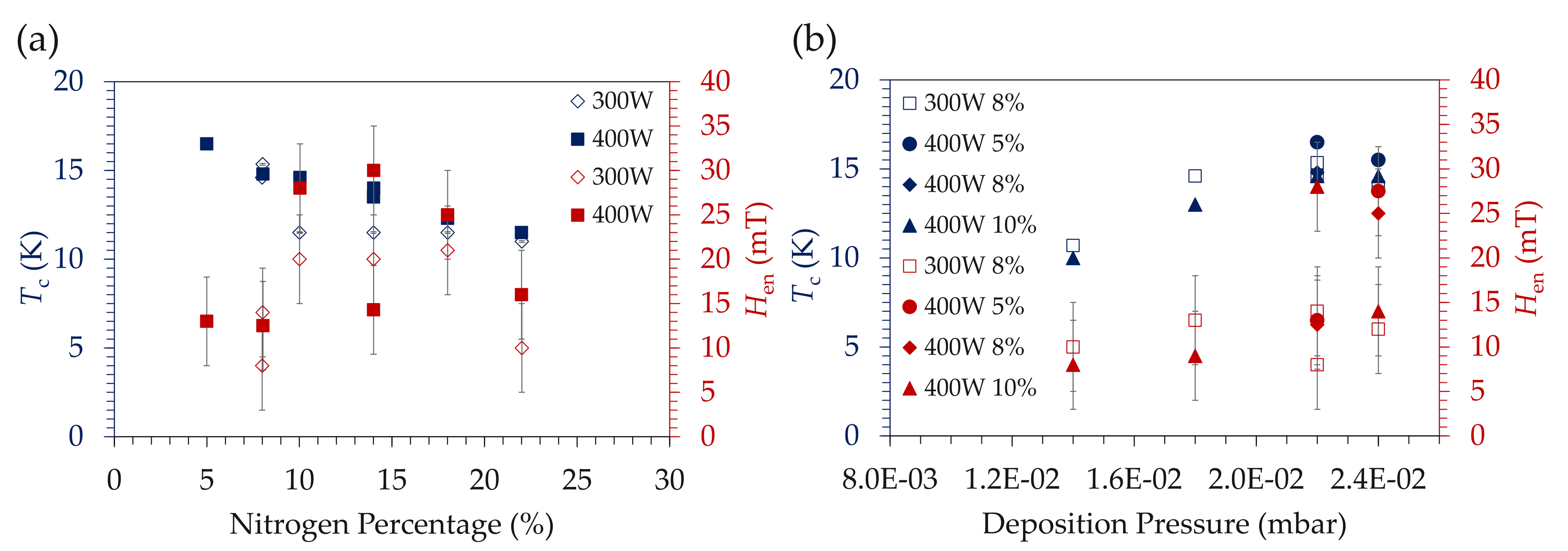


**Figure 4:** Plots detailing the change in the critical temperature and the entry field of HiPIMS NbN samples, in parallel field, as a function of (a) increasing nitrogen percentage and (b) increasing deposition pressure.

## Conclusions

- A high deposition pressure, low cathode power, low $N_2$% and intermediate substrate bias (< 75 V) result in preferential δ-NbN (111) deposition.
- HiPIMS deposited films display significant density improvements compared to DC MS films, in spite of the higher deposition pressure required.
- The improved density and surface roughness of HiPIMS-deposited films results in $H_{en}$ > bulk NbN $H_{c1}$ and significant improvements over DC MS NbN films.
- Optimised coating utilised during deposition of HiPIMS SIS films, see **SUPFDV012**

## References

[1] S. Leith, *et al*, "Superconducting NbN thin films for use in superconducting radio frequency cavities," *Supercond. Sci. Technol.*, vol. 34, no. 2, 2021
[2] A.-M. Valente-Feliciano, "Superconducting RF materials other than bulk niobium: a review," *Supercond. Sci. Technol.*, vol. 29, no. 11, 2016.

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