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NIOBIUM SPUTTER-COATED QWRs

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DC biased diode sputtering is a well-suited technique for producing niobium coated copper quarter wave resonators. The coating procedure is well-established for cavities of the high-beta section of the LNL LINAC ALPI. High purity niobium films are deposited by DC diode sputtering with negative bias electrode. By acting on deposition parameters and on substrate quality, four resonators with an average accelerating field of over 7 MV/m at 7 W have been fabricated and are ready for installation in ALPI.

Keywords: Superconductivity; Radiofrequency; Cavities; Niobium; Sputtering

1 HISTORY OF NIOBIUM SPUTTERED COPPER QUARTER-WAVE RESONATORS AT LNL

The research activity on niobium sputtered copper quarter-wave resonators (QWRs) at LNL began in 1988 when a laboratory dedicated to the application of sputtering technologies to the production of high quality QWRs was created. On the basis of CERN experience with electron cavities for LEP[1] the new technology for niobium on copper QWRs was developed using DC biased diode sputtering technique. The bias promotes the ion bombardment of the growing film meanwhile washing out those impurities weakly bonded to the crystalline lattice.

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The main steps of this research are listed below:

1988 – UHV sputtering system set-up; study on small size samples placed into a dummy cavity;
1991 – first Nb sputtered copper prototype;
1993 – three prototypes overcome 6 MV/m at 7 W;
1994 – design and test of resonator for installation (coupler, beamports, bottom plates);
1995 – production and installation of four resonators in ALPI Cryostat 20, beamline test (after conditioning 3.9–4.5 MV/m at 7 W);
1996 – improved sputtering procedure, new design and test of resonator for installation (coupler, pickup, collar), production of copper substrates;
1997 – production of four resonators (Laboratory test 5.7–7.7 MV/m at 7 W).

The $Q(E_{acc})$ curves for the two sets of resonators produced in 1995 (beamline test) and 1997 (Laboratory test) are presented in Figure 1. For the best resonator HB 1.3 Q-value versus the peak fields is displayed in Figure 2.

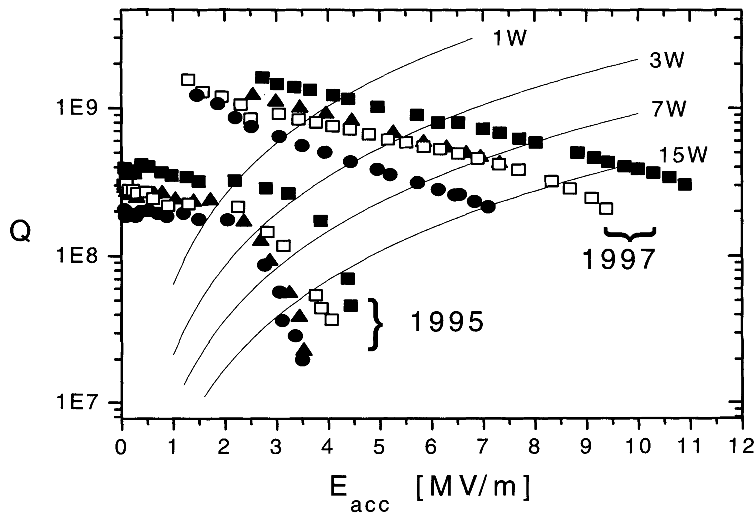

FIGURE 1 $Q(E_{acc})$ curves for the new set of 4 cavities to be installed in ALPI high-beta section (Laboratory test) in comparison with the curves of in-line test of the cryostat CR 20 cavities installed in 1995.

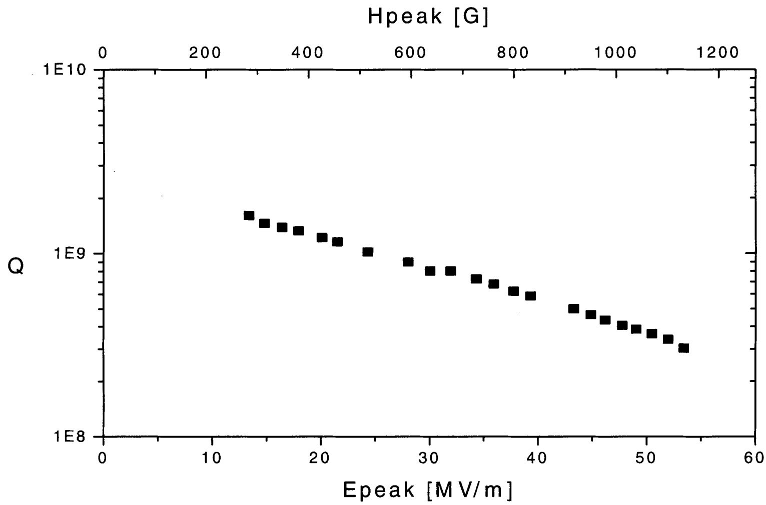

FIGURE 2 Q-factor versus electric peak field and magnetic peak field for the cavity HB 1.3 (Laboratory test).

2 PRODUCTION SEQUENCE

The production sequence for HB 1.1–HB 1.4 resonators for ALPI high-beta section is as follows:

Substrate – machined from an OFHC 99.99% copper billet.

- Preliminary tumbling (2 days).
- Frequency fine adjustment.
- Tumbling (5–7 days).
- High pressure ultrapure water rinsing 100 bar (HPR).
- Electropolishing (10 μm) + HPR.
- Chemical polishing (SUBU) + HPR.
- Passivation + HPR.
- Rinsing with alcohol, drying with nitrogen.
- Degassing in UHV at 500°C.
- Sputtering + HPR.
- Rinsing with alcohol, drying with nitrogen.
- Laboratory test

  Multipacting conditioning: 2–6 h.

  Helium conditioning: 2–3 h.

3 SUBSTRATE MATERIAL CHARACTERISTICS

The quality of copper substrate is of crucial importance for producing high quality sputtered QWRs. Copper purity, thermal conductivity, microstructure, porosity have been found to influence the final cavity performance. In order to show the integral effect of substrate characteristics we present the heating with accelerating field data for two cavities: one of our best prototypes (Prot. 11, 1993[2]) and the cavity from the last produced set (HB 1.2, 1997), which have very similar $Q(E_{acc})$ curves (Figures 3 and 4).

It can be seen that the temperature of Prototype 11 rises with accelerating field while the cavity HB 1.2 is efficiently cooled and remains near 4.2 K even at maximum accelerating field. The differences between the two are listed below:

Prototype 11
- Copper SE CU 99.95%.
- Brazed external cylinder.

Resonators of HB-series
- Copper OFHC 99.99% certified grade.
- No brazings.
- Improved quality and uniformity of Nb film.

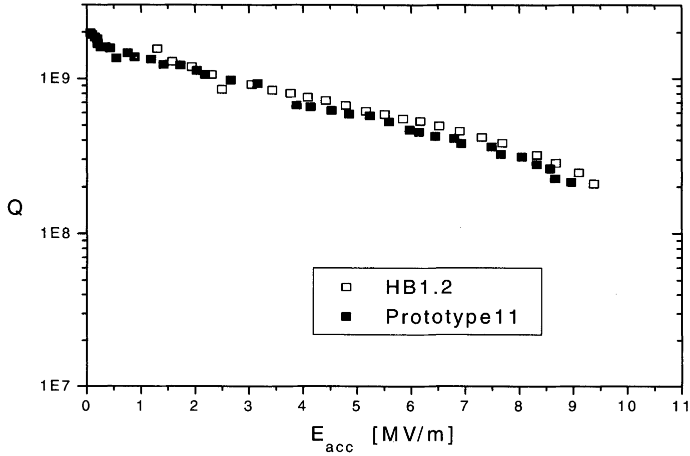

FIGURE 3 $Q(E_{acc})$ curves for our best prototype Prot. 11 and the new cavity HB 1.2 ready for installation (Laboratory test).

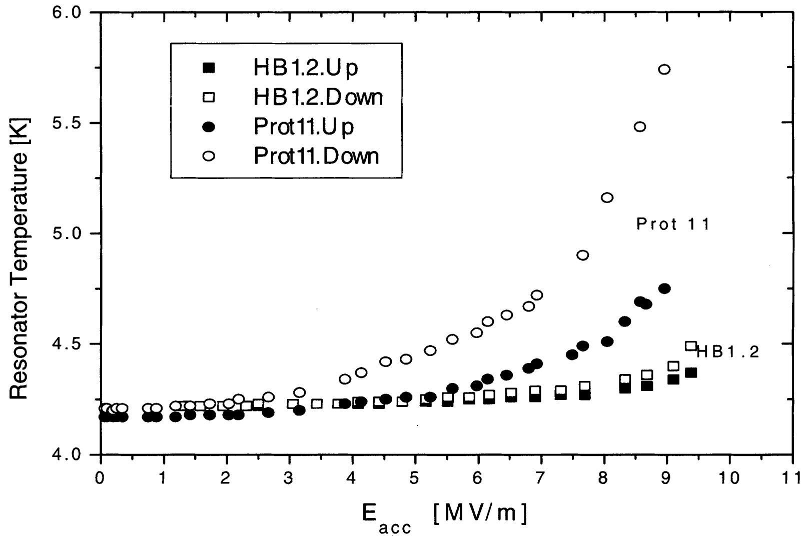

FIGURE 4 Temperature dependence on the accelerating field for up and down part of Prototype 11 and cavity HB 1.2 (Laboratory test).

4 NEW DESIGN OF THE RESONATOR FOR HIGH-BETA ALPI SECTION

On the basis of production and operating experience with the first set of sputtered cavities, installed in 1995,[3] several changes in the production procedure and resonator geometry have been made (Figure 5). Resonator with collar and mounting blocks is machined from OFHC copper billet. The capacitive coupler and pick-up have been transferred from the bottom plate to the external cylinder at a level slightly lower than the end of the central shaft. The advantages of this solution in comparison with the previous one are the following:

Resonator

- Arrives from mechanical workshop “ready to use”.
- All previosly brazed elements are excluded.
- Absence of hidden volumes in the brazings.
- OFHC copper is not contaminated during brazings.
- Improved thermal conductivity of substrate.

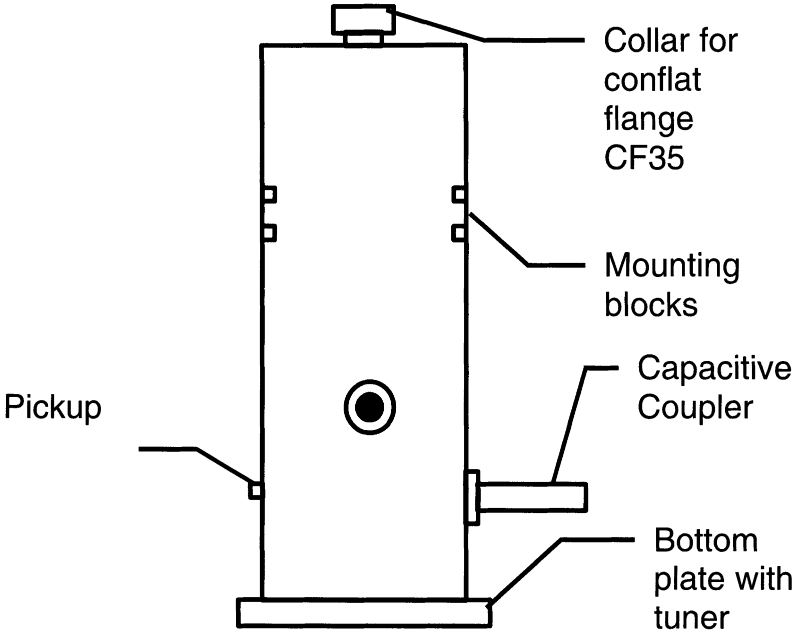

FIGURE 5 New design of the cavity for ALPI high-beta section.

Lateral capacitive coupler
- Excludes interdependence between coupling and tuning.
- Makes more simple and reliable coupler mechanics.
- Does not limit the resonator performance.

5 SPUTTERING PARAMETERS, CONFIGURATION AND GUIDELINES FOR BIAS SPUTTERING OF QWRs

The sputtering configuration is shown in Figure 6 and is discussed in detail in.[2,3] The sputtering parameters used for the resonators of HB-series are as follows:

Base vacuum	5×10^{-9} mbar,	Total time	4 h,
Argon pressure	0.2 mbar,	Number of runs	8,
Discharge	700 V, 6 A,	Temperature	300–500°C,
Bias	120 V, 6 A,	Film thickness	2–3 μm.

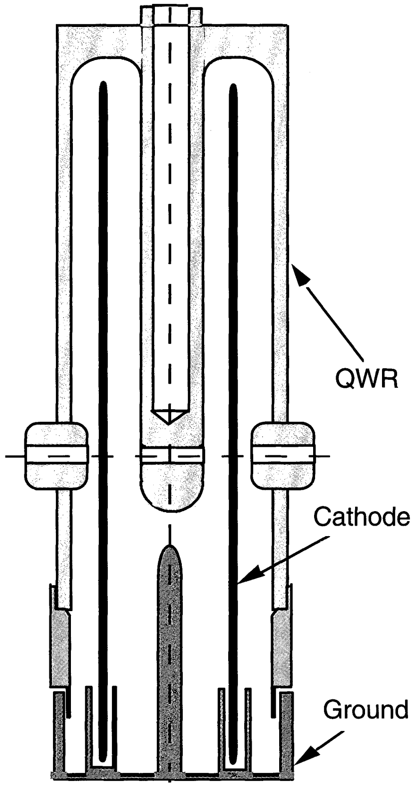

FIGURE 6 The sputtering configuration.

Bias sputtering:

Nb is contaminated with impurities in the zones where bias is not effective
– *avoid sharp angles in resonator geometry, especially in high current regions.*

Relatively low deposition rate
– *ultrahigh vacuum, baking temperature must be higher than the deposition one.*

Sputtering configuration:

Film peeling at the end of shaft due to electron bombardment
– *mirror electrode for the shaft with bias potential.*

Different plasma parameters inside and outside cathode-plasma holes, dark rings

– *high pressure of argon.*

Spikes:

– *special design of high voltage feedthrough,*
– *cathode isolators in boron nitride.*

Powders:

– *clean chamber, slow pumping down and venting,*
– *high pressure rinsing after deposition.*

6 CONCLUSIONS

A well established production sequence for niobium sputtered QWRs for high-beta section of ALPI LINAC has been developed at LNL. Four resonators with new optimized design and accelerating fields around 7 MV/m at 7 W have been fabricated and are ready for installation in ALPI.

It has been demonstrated that thin film niobium sputtered resonators can achieve very high levels of surface peak fields ($E_{\mathrm{peak}} \cong 53$ MV/m, $H_{\mathrm{peak}} \cong 1150$ G) even under small scale production conditions.

References

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