Niobium coatings for 1.5 GHz RF cavities

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Abstract

The cylindrical magnetron sputtering configuration used for coating the LEP 200 RF cavities (of 352 MHz frequency) has been adapted to coat 1.5 GHz cavities, of interest for future linear colliders.

Two different cathode diameters have been considered, namely 30 and 40 mm.

The optimization of the coating procedure, still in progress, showed that RRR values up to 17 could be obtained on samples.

The obtained film thickness uniformity is within a factor 1.5.

The chemical treatment of the copper cavity prior to Nb coating is also under study; coating of real cavities is planned for the end of 1993.

1. Introduction

A study carried out at CERN since 1980 has demonstrated the feasibility of producing Nb-coated copper superconducting RF cavities [1].

The niobium film, about 1.5 μm thick, is deposited by sputtering in a cylindrical magnetron configuration. The history and the present status of this development are described elsewhere [2, 3].

When compared to superconducting cavities traditionally made from niobium sheet, Nb-coated copper cavities provide higher stability against quench, insensitivity to trapped earth magnetic field and higher value of unloaded quality factor Qo for a lower cost. Thanks to these advantages, Nb-coated cavities have been adopted for the energy upgrade of LEP in the framework of the LEP 200 project at CERN. About 170 cavities of this type are presently under production by three different European firms.

Development work is presently under way in other laboratories [4, 5] to adapt this technique to coating cavities of higher frequency (1.3 – 1.5 GHz) as required for future linear colliders.

The interest of the coating approach for this application is however questionable because of the following reasons. The higher Qo value at low accelerating fields of the Nb-coated cavities deteriorates with increasing field, to become less than that of Nb sheet cavities above about 10 MV/m.

This feature, which is detrimental but still tolerable for LEP cavities operating at 6 MV/m, is not acceptable for future linear colliders which require much higher accelerating fields. Furthermore, higher frequency cavities are usually cooled to below 4.2 K to reduce the BCS term of their surface resistance and the related cryogenic losses. Under these conditions the higher initial BCS Qo value of the Nb-coated cavities no longer represents an advantage.

However the higher stability against quench provided by the Nb-coated cavities renders this solution very attractive for high accelerating field applications. Recent statistics from large scale production of 1.5 GHz cavities [6] indicate that quenching is still a major cause of field limitation above 10 MV/m in spite of the steadily improving purity of the niobium used for their construction. Furthermore, higher frequency cavities provide an easier way to study fundamental phenomena (like the Qo degradation at high accelerating fields) because of the easier handling and the reduced risk of accidental contamination consequent to their smaller dimensions. For these reasons a study has been undertaken at CERN on the Nb coating of 1.5 GHz copper cavities. The results obtained so far are described below.

2. *Coating system and sputtering configuration*

The coating system, schematically shown in Fig. 1, is all metal, bakeable to 300 °C and pumped by a turbomolecular pumping station of 200 ℓ/s nominal pumping speed. The ultimate pressure achieved after bakeout is lower than 10^{-9} mbar. Up to four samples may be coated in a single run under different discharge conditions thanks to a stainless steel cavity equipped with a rotatable sample holder at the equatorial plane. Gas analysis during coating is made possible by a quadrupole gas analyser linked to the main system by a low conductance orifice and differentially pumped by a second turbomolecular pump of 50 ℓ/s nominal pumping speed.

The sputtering configuration adopted for the present study is a cylindrical magnetron similar to that used for LEP cavities [2] but reduced in size to cope with the smaller cavity dimensions. The inner diameter of the cavity cut-off tubes sets a safety upper limit of 40 mm to the cylindrical cathode internal diameter (outer diameter of the niobium liner about 50 mm). On the other hand, a cathode diameter smaller than about 30 mm would render the insertion and the cooling of the magnetron electromagnet unduly difficult. Cathodes of both 30 and 40 mm internal diameter have been built and tested for further evaluation with respect to coating thickness uniformity, magnetic field intensity, discharge characteristics and Nb film residual resistivity ratio (RRR) value.

The calculated thickness profiles and some measured values are shown in Fig. 2. These data indicate that for both cathode geometries the coating thickness variation is within a factor 1.5, though slightly smaller for the 40 mm diameter cathode.

The dependence on the magnet current intensity of the axial component of the magnetic flux density measured on the surface of the cathode at the central point of the electromagnet is shown in Fig. 3. For both cathode diameters the magnetic flux density displays the same linear dependence on magnet coil current intensity, but the smaller magnet is limited to lower currents by iron core saturation.

The longitudinal profile of the magnetic flux density axial component on the surface of the cathode is shown in Fig. 4.

This component of the magnetic field density is quite constant over the central part of the magnet, a feature which provides good discharge conditions. The variation of the discharge current intensity as a function of the cathode potential and for various argon discharge pressures is shown in Fig. 5 for the 30 mm diameter cathode and in Fig. 6 for the 40 mm diameter cathode.

The 1100 watt line represented in these figures corresponds to a deposition rate about three times larger than the corresponding value adopted for the coating of LEP cavities if scaled according to the ratio of the cavity surface areas. Power values above this limit result in discharge instability possibly due to cathode overheating. From these data it may be concluded that very high sputtering rates may be obtained for both cathode dimensions at reasonably low cathode potentials.

In conclusion, the two cathode geometries here considered are practically equivalent in all respects, and therefore both have been used to produce Nb-coated samples for RRR evaluation.

3. *The RRR of the Nb-coated samples*

The preliminary results obtained with both cathodes are shown in Figs. 7, 8 and 9. Although more measurements are needed to obtain the optimum coating conditions and come to a final choice of the cathode diameter, the RRR values obtained so far are comparable to those obtained for the LEP cavities. The reported data confirm that higher RRR values may be obtained at low discharge argon pressure and low cathode voltage, as already noticed for the LEP cavities. It is also confirmed that the RRR values quickly decrease when decreasing the thickness of the niobium film below 1.5 μm due to decreasing size of Nb film grains [3].

4. *Conclusions*

Good quality niobium coatings with RRR values up to 17 have been produced by means of cylindrical magnetron sputtering inside a 1.5 GHz cavity. The two different cathodes, of 30 and 40 mm internal diameters, which have been used are equivalent both in terms of discharge characteristics and of film quality. More work is needed to define the optimum coating conditions. Real cavities will be coated before the end of 1993.

5. *Acknowledgements*

This work has been carried out in the framework of a CERN-INFN collaboration for the production of 1.5 GHz cavities for future linear colliders. The authors are indebted to J. Genest for helping with the mechanical design of the coating system.

References

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Figure Captions

Fig. 1 Schematic view of the coating system.

Fig. 2 Calculated Nb film thickness profiles for 30 mm (empty circles) and 40 mm (full triangles) cathode diameters. Dots represent measured values for coatings carried out with the 30 mm internal diameter cathode.
The thick continuous line (left vertical axis) represents the cavity meridian profile. The lengths of the magnets are 56 and 76 mm for the 30 and 40 mm diameter cathode respectively.

Fig. 3 Axial component of magnetic flux density measured on cathode surface at the central point of the electromagnet. The deviation from the linearity is due to iron core saturation.

Fig. 4 Longitudinal profile of the magnetic flux density axial component on the surface of the cathode. The triangles represent the measured values, the full line the calculated profile. Cathode diameter 40 mm, magnet current intensity 30 A, magnet length 76 mm.

Fig. 5 Discharge current I_C versus cathode potential U_C for 30 mm diameter cathode, 60 A coil current and various argon discharge pressures.

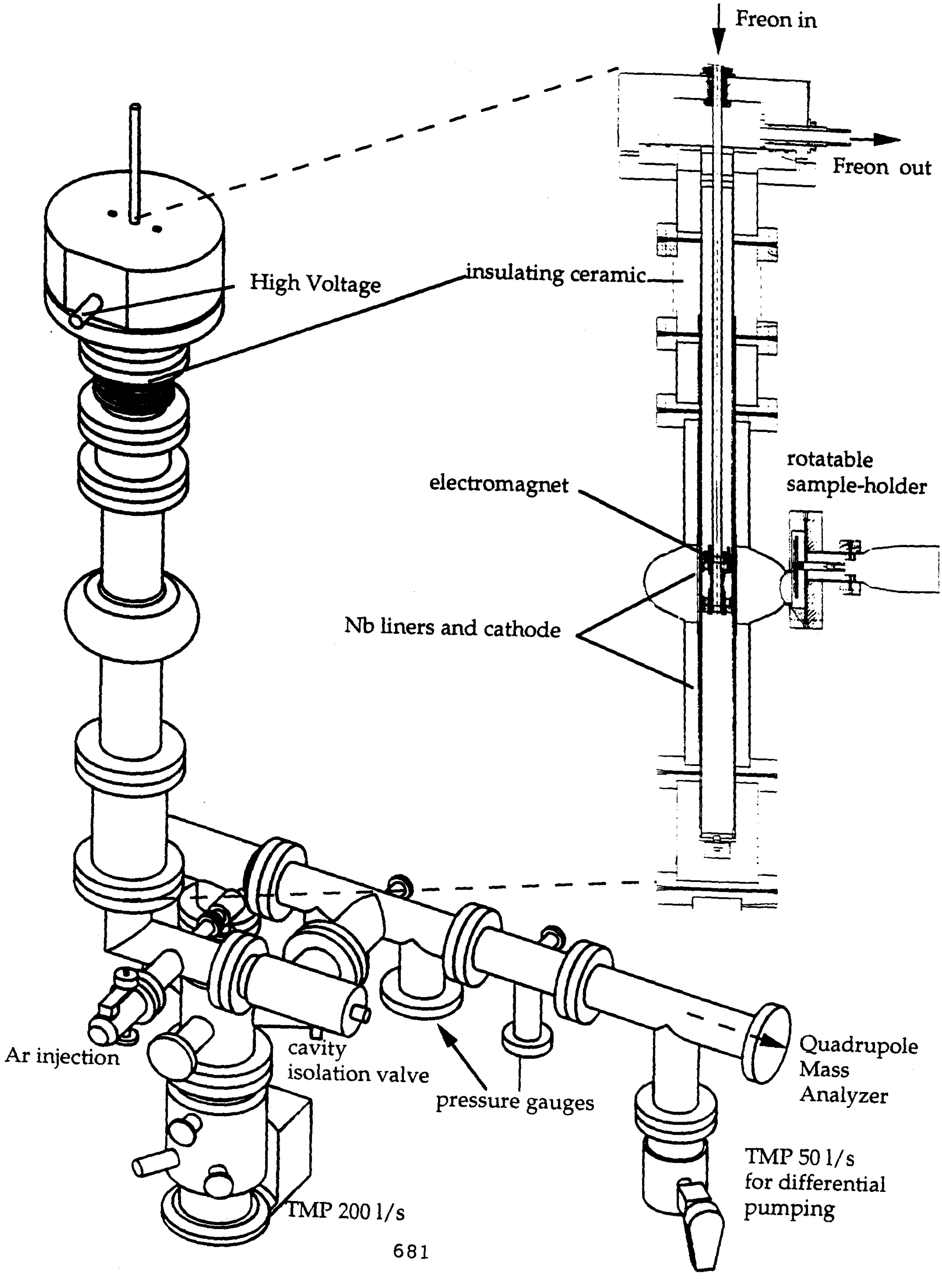
Fig. 6 Discharge current I_C versus cathode potential U_C for 40 mm diameter cathode, 75 A coil current and various argon discharge pressures.

Fig. 7 Variation of Nb film RRR as a function of the argon pressure p_{Ar} during discharge for the 40 mm diameter cathode. Film thickness 1 µm. Coating temperature 200 °C, cathode potential - 440 V and discharge current 2.5 A (discharge power 1100 W).

Fig. 8 Variation of Nb film RRR as a function of cathode voltage U_C for the 40 mm diameter cathode. Film thickness 1 µm. Coating temperature 200 °C, argon pressure $2.5 \cdot 10^{-3}$ mbar and discharge power 1100 W.

Fig. 9 Variation of Nb film RRR as a function of thickness for the 30 mm cathode diameter. Coating temperature 200 °C, cathode voltage -450 V, discharge current 2.45 A (discharge power 1100 W) and argon pressure $5 \cdot 10^{-3}$ mbar.

Fig. 1


Freon in
Freon out
High Voltage
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electromagnet
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pressure gauges
Quadrupole
Mass
Analyzer
TMP 50 l/s
for differential
pumping
TMP 200 l/s

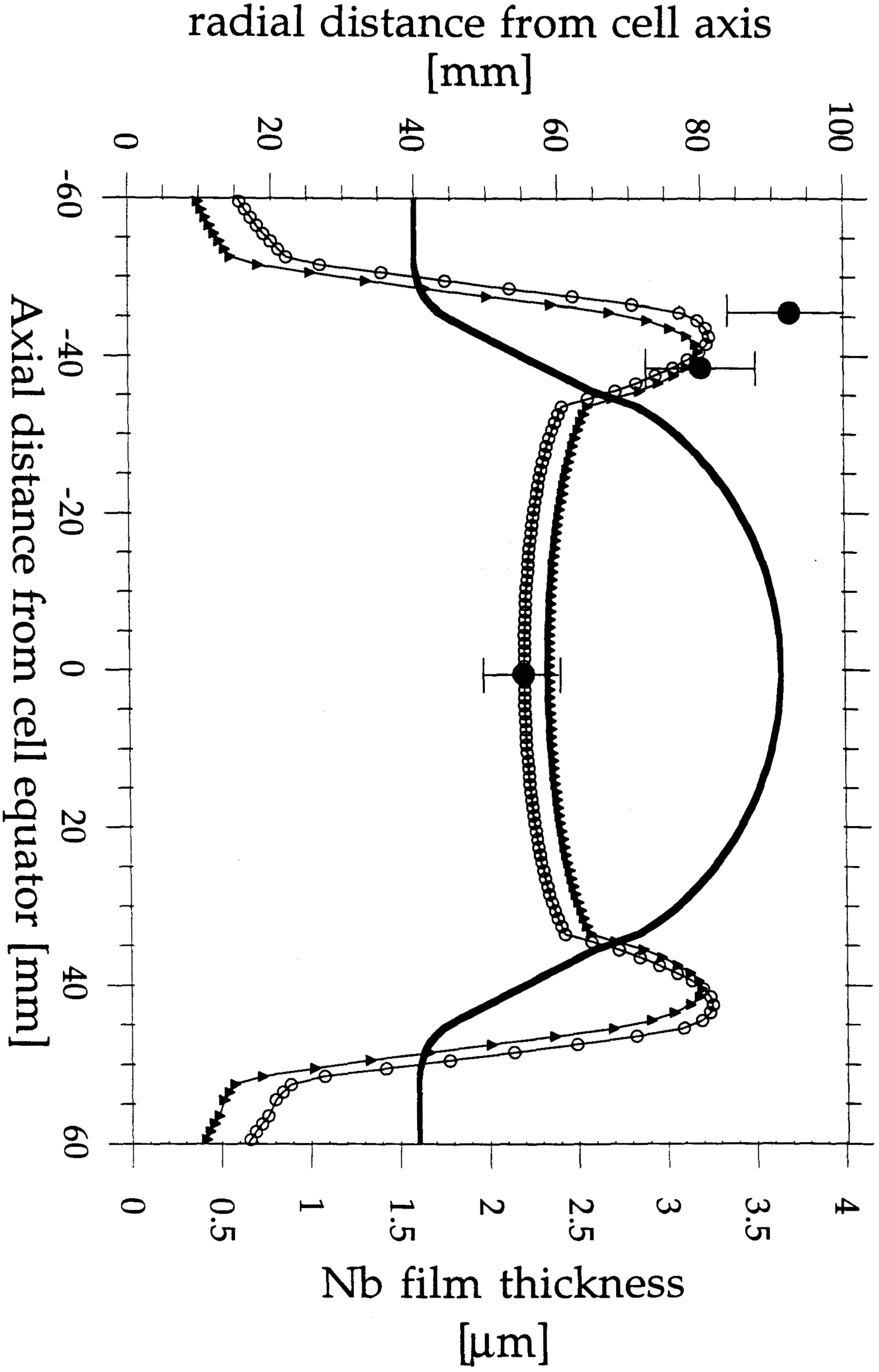

radial distance from cell axis
[mm]
0
20
40
60
80
100
-60
-40
-20
0
20
40
60
Axial distance from cell equator [mm]
0
0.5
1
1.5
2
2.5
3
3.5
4
Nb film thickness
[μm]

Fig. 2

Fig. 3

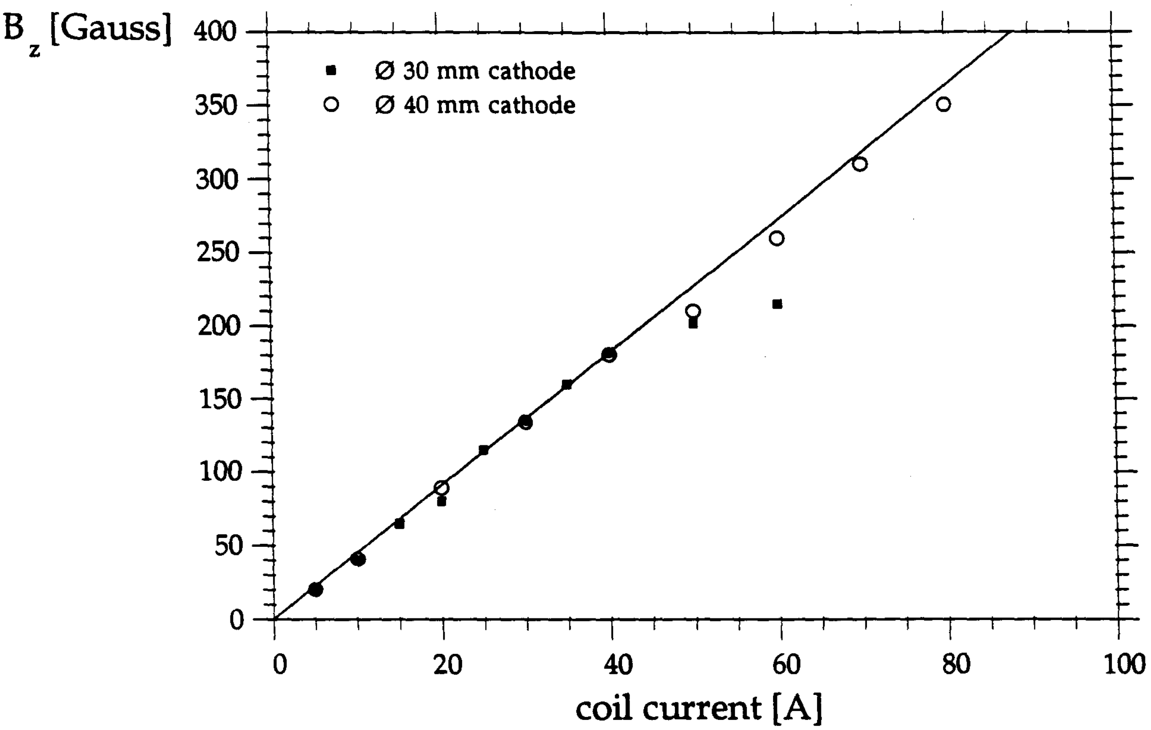
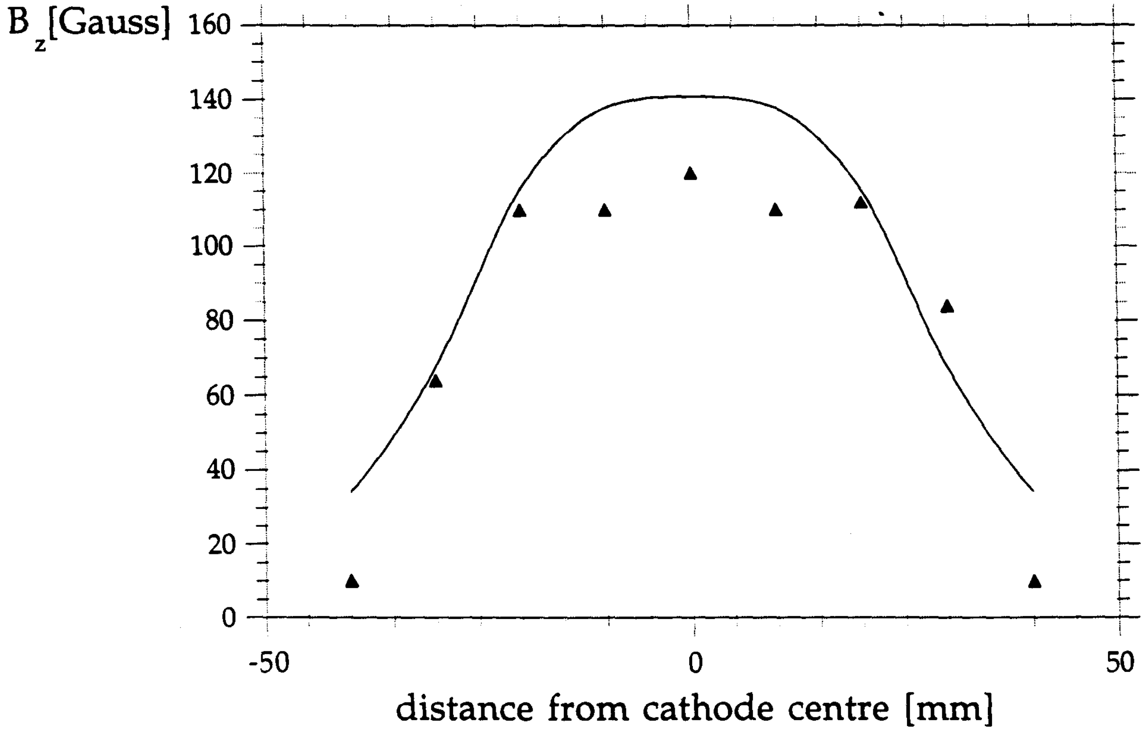

B_z [Gauss]
400
350
300
250
200
150
100
50
0
■ Ø 30 mm cathode
○ Ø 40 mm cathode
0
20
40
60
80
100
coil current [A]

Fig. 4


B_z[Gauss]
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140
120
100
80
60
40
20
0
-50
0
50
distance from cathode centre [mm]

Fig. 5

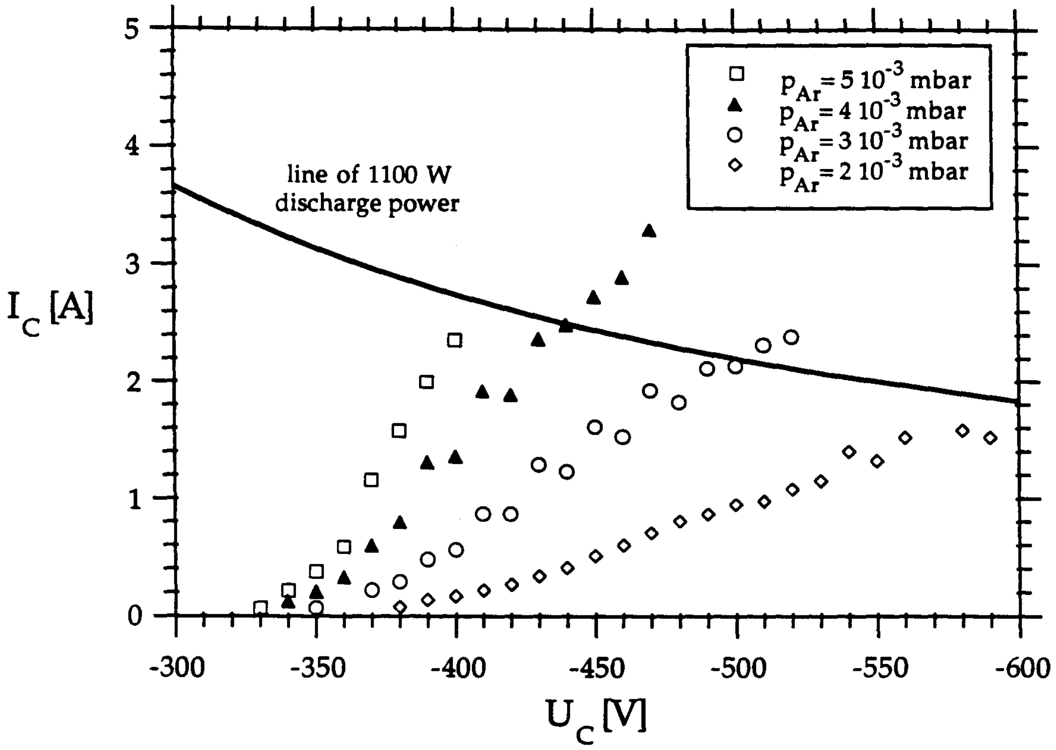
p_{Ar}= 5 10^{-3} mbar
p_{Ar}= 4 10^{-3} mbar
p_{Ar}= 3 10^{-3} mbar
p_{Ar}= 2 10^{-3} mbar
line of 1100 W
discharge power
I_C [A]
U_C [V]
0
1
2
3
4
5
-300
-350
-400
-450
-500
-550
-600

Fig. 6

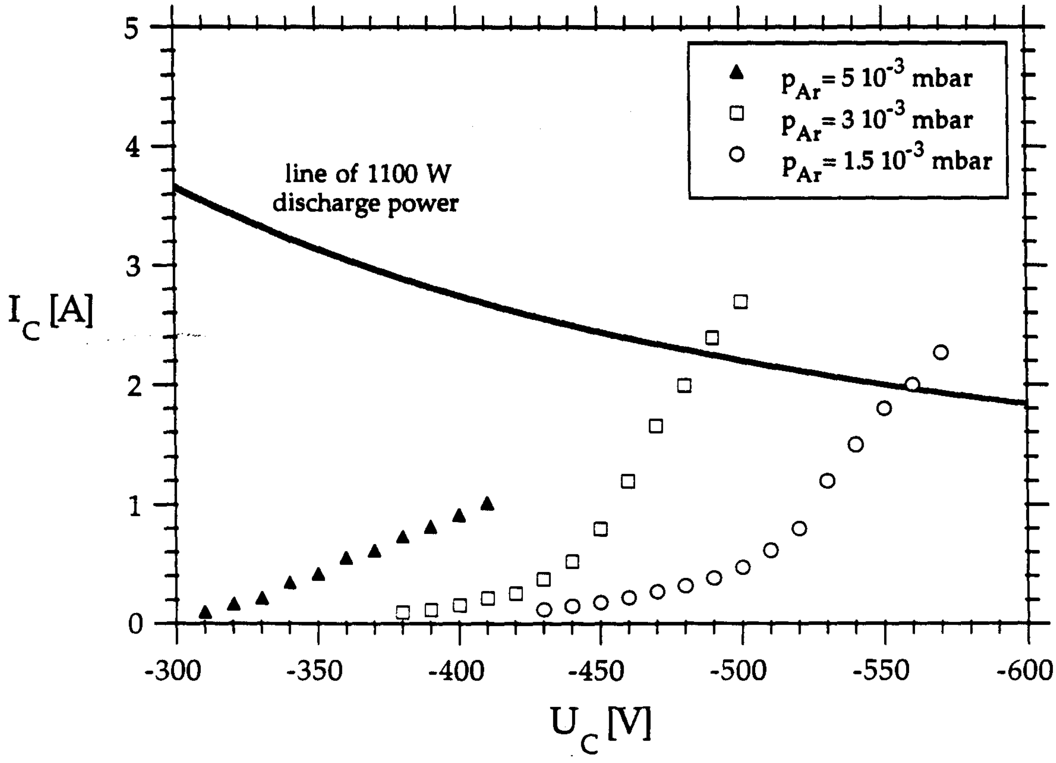
p_{Ar}= 5 10^{-3} mbar
p_{Ar}= 3 10^{-3} mbar
p_{Ar}= 1.5 10^{-3} mbar
line of 1100 W
discharge power
I_C [A]
U_C [V]
0
1
2
3
4
5
-300
-350
-400
-450
-500
-550
-600

Fig. 7

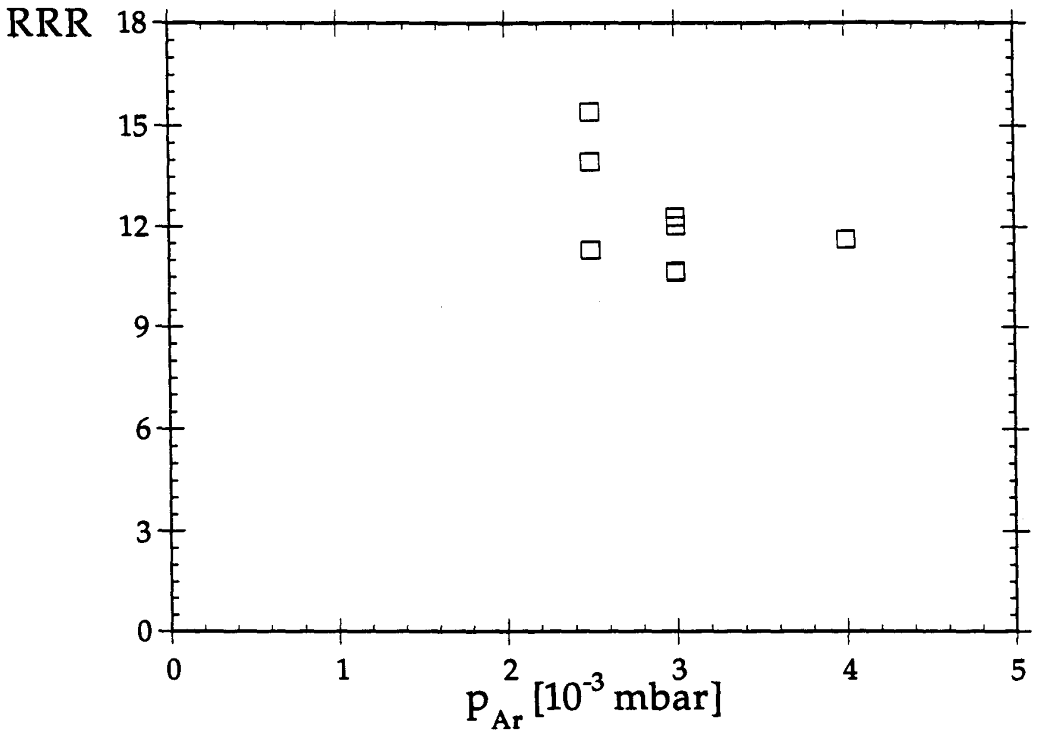
RRR
18
15
12
9
6
3
0
0
1
2
3
4
5
p_{Ar} [10^{-3} mbar]

Fig. 8

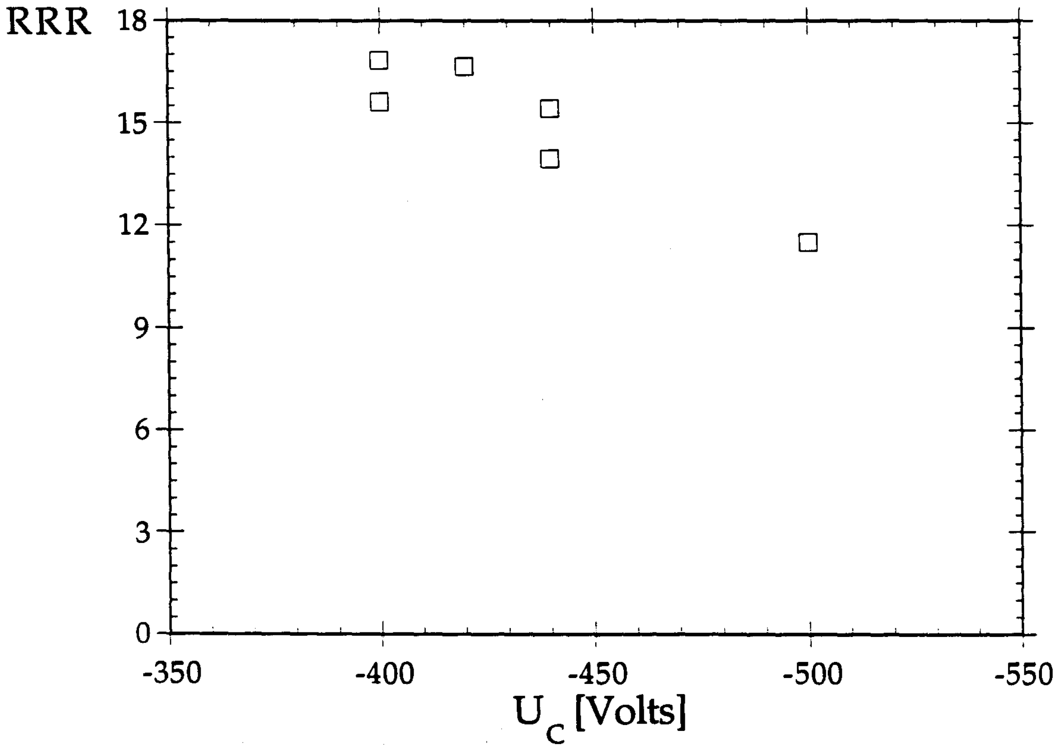
RRR
18
15
12
9
6
3
0
-350
-400
-450
-500
-550
U_C [Volts]

Fig. 9