TESLA Reports are available from:
Deutsches Elektronen-Synchrotron DESY
MHF-SL Group
Katrin Lando
D-22603 Hamburg
FRG

Phone: (+49/40) 8998 3339
Fax: (+49/40) 8998 4302
e-mail: katrin.lando@desy.de
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# Programme

## 3\textsuperscript{rd} Joint DESY-LAL Saclay Workshop on High Power Couplers for TESLA

### Monday 17th - Salle Bleue (Bât. 200)

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<th>Speaker</th>
<th>Topic</th>
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<td>Introduction</td>
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<tr>
<td>09:45 - 10:00</td>
<td>J. Sekutowicz</td>
<td>Update on coupler specification for the TTF Superstructure</td>
</tr>
<tr>
<td>10:00 - 10:25</td>
<td>B. Dwersteg</td>
<td>Coaxial input coupler design for the TTF Superstructure</td>
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<tr>
<td>10:25 - 10:55</td>
<td>Coffee Break</td>
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<td>10:55 - 11:20</td>
<td>M. Dohlus</td>
<td>Design of waveguide couplers for the TESLA Superstructure</td>
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<td>11:20 - 11:45</td>
<td>A. Zavadsev</td>
<td>A rectangular waveguide input coupler for the Superstructure</td>
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<td>11:45 - 12:15</td>
<td>P. Laperesq</td>
<td>Low level measurements of reduced height waveguide transition</td>
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<td>12:15 - 13:45</td>
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<td>13:45 - 14:15</td>
<td>L. Grandifl</td>
<td>The Orsay - Saclay coupler design</td>
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<td>14:15 - 14:45</td>
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<td>General discussion on new coupler designs</td>
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<td>14:45 - 15:10</td>
<td>D. Kostine</td>
<td>TTF linac ACC1 (module 3) input coupler performance</td>
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<td>15:10 - 15:30</td>
<td>C. Martens</td>
<td>Experience with manufacturing coaxial input couplers for TESLA</td>
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<td>15:30 - 16:00</td>
<td>C. Travier</td>
<td>Coffee Break</td>
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<tr>
<td>16:00 - 16:45</td>
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<td>Results from the TW window tests (titanium version)</td>
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<tr>
<td>16:45 -</td>
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<td>General discussion</td>
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<tr>
<td>Time</td>
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<td>Topic</td>
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<tr>
<td>9:30 - 9:50</td>
<td>M. Lalayan</td>
<td>Argon discharge treatment of TTF input</td>
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<tr>
<td>9:50 - 10:15</td>
<td>S. Iariguine</td>
<td>Conditioning of TTF input couplers</td>
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<td>10:15 - 10:45</td>
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<td>Coffee Break</td>
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<tr>
<td>10:45 - 11:15</td>
<td>C. Travier</td>
<td>Results of the tests on the second $\lambda/2$ window</td>
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<tr>
<td>11:15 - 11:35</td>
<td>N. Rouvière</td>
<td>Conditioning couplers and preventive measures</td>
</tr>
<tr>
<td>11:35 - 12:05</td>
<td></td>
<td>Open discussion on conditioning</td>
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<tr>
<td>12:05 - 12:30</td>
<td>G. Devanz</td>
<td>Multipactor simulations</td>
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<tr>
<td>12:30 - 14:00</td>
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<td>Lunch</td>
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<tr>
<td>14:00 - 14:20</td>
<td>D. Proch</td>
<td>Multipacting measurement with a TiZrV coated Cu sample</td>
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<tr>
<td>14:20 - 14:45</td>
<td>A. Zavadtsev</td>
<td>RF losses in a Cu surface with TiZrV coating</td>
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<td>14:45 - 15:10</td>
<td>J. Lorkiewicz</td>
<td>Recent activities in TiN coating of ceramic RF power elements at DESY</td>
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<td>15:10 - 15:40</td>
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<td>Coffee Break</td>
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<tr>
<td>15:40</td>
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<td>AGB</td>
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<td>Future developments</td>
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<td></td>
<td>Conclusions</td>
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Summary of the TESLA Input Coupler Workshop,

This meeting was the third in a series of joint Orsay - Saclay - DESY workshops on the input coupler. The aims of these meetings are to exchange ideas and to share information obtained on the respective coupler test stands at DESY and Saclay. The specification of the TESLA coupler is continuously changing in response to the changing parameters of the machine. Calculations (Sekutowicz) show that, if the cavity stiffening cannot be increased, the superstructure would need to transmit 2.6 MW for the parameters of TESLA 800! Clearly increased stiffening is absolutely necessary. Various new coupler designs were presented.

- an upgraded version of the DESY co-axial coupler intended for the superstructure (Proch),
- Computational studies of waveguide couplers (Dohlus, Zavadjsev),
- The co-axial design from the French collaboration (Grandsire).

The Orsay-Saclay coupler proposal provoked little criticism from the meeting participants implying that the principle of the design is considered reasonable. It employs a reduced height waveguide transition for which some low level measurements were presented. A high power test is foreseen in March. The choice of cold window for the French design is still undecided. The existing candidates are (i) the $\lambda/2$ window, (ii) the travelling wave window, and (iii) a DESY-like cold window. A rather new topic of discussion was a comparison of the degree of RF « kick » transmitted to the beam by the co-axial and waveguide options. This has still to be assessed.

The DESY group have now obtained considerable experience with coupler manufacturing (Martens), conditioning (Lariguine) and testing on modules with the TESLA Test Facility (Kostine). The talk by Martens illustrated the numerous procedures necessary to produce the finished object – machining, cleaning, welding, brazing, copper plating, metallisation, TiN deposition etc. The French group still have the pleasure of this work ahead of them. The results of the first tests of a TW wave window were shown (Travier). The relative merits and disadvantages of such a window were outlined. The window was tested both in SW and TW operation and illustrated a rather fast conditioning time to 1 MW. Nevertheless some multipactor barriers persist although these are thought to be due to the co-axial line. Conditioning couplers remains a subject of great importance as experience to date shows that it takes far too long. Tests on TTF couplers at DESY seem to indicate that an argon discharge treatment can reduce the conditioning period (Lalayan). Many of the conditioning issues in the coupler have similarities with conditioning of vacuum systems for electron storage rings. Studies at the ESRF have demonstrated hysteresis effects after conditioning with RF power and baking (Rouvière). The importance of cleanliness and venting under dry nitrogen was noted if one wishes to preserve, at least partially, the effects of conditioning.
Vacuum pumping might be improved by Non-Evaporable Getter (NEG) pumps. Work at CERN, by Ch. Benvenuti, is in progress on thin film NEG coatings (D. Proch). However, the question of RF losses in the coating and creation of «dust» particles has to be answered. There are indications that such a coating might be useful in the struggle against multipactor. A new 2-D code was described for the calculation of multipactor. The code has been written to study multipacting in proton linac cavities but will be useful also for window studies. It would be nice to have a comparison between this code and the Helsinki code for a given problem. A likely candidate for an NEG coating would be compounds of TiZr. Calculations and measurements of RF losses for a coating of TiZrV are being performed at DESY (Zavadsev). Preliminary results show that the increased RF losses might be acceptable in view of the advantages gained for conditioning and multipactor. TiN coating of ceramics is essential to avoid multipactor. The French group has established a coating procedure along with an industrial partner, as discussed in an earlier meeting. In contrast, DESY perform their own TiN coating. Experience with coating waveguide windows and cylindrical coupler windows with Ti in the vapour phase was discussed and the apparatus described (Lorkiewicz).

Action points

It was agree that by the next meeting we would attempt to:

- Establish a data base for ceramics (All institutes).
- Find a way to validate multipactor codes (Travier, Proch).
- Evaluate the transverse kick given to the beam (M. Dohlus).
- Set up a measurement of ε and tan δ (DESY).
- Learn as much as we can about conditioning from experience on e+e- storage rings.

The next meeting should take place at DESY in September 2000.

T. Garvey, Orsay 25-02-2000
## Workshop Participants

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
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<tbody>
<tr>
<td>M. Dohlus</td>
<td>DESY</td>
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<td>S. Iariguine</td>
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<td>D. Kostine</td>
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<td>M. Lalayan</td>
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<td>J. Lorkiewicz</td>
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<td>C. Martens</td>
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<td>W.D. Möller</td>
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<td>D. Proch</td>
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<td>J. Sekutowicz</td>
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<td>A. Zavadtsev</td>
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<td>J.C. Bourdon</td>
<td>LAL-Orsay</td>
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<td>T. Garvey</td>
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<td>L. Grand'isire</td>
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<td>P. Lepercq</td>
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<td>J. Le Duff</td>
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<td>G. Mace</td>
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<td>J. Marini</td>
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<td>R. Panvier</td>
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<td>F. Richard</td>
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<tr>
<td>B. Aune</td>
<td>CEA-Saclay</td>
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<td>P. Boachon</td>
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<td>S. Chel</td>
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<td>N. Colombel</td>
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<td>M. Desmons</td>
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<td>G. Devanz</td>
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<td>C. Travier</td>
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<tr>
<td>T. Junquera</td>
<td>IPN-Orsay</td>
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<tr>
<td>N. Rouvière</td>
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</tbody>
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UPDATE ON INPUT COUPLER SPECIFICATION FOR THE TESLA SUPERSTRUCTURE

J. Sekutowicz, DESY

I  Schedule for the first Nb prototype and specification for the FM coupler

II  FM coupler for the TESLA 500 and TESLA 800: Specification
Schedule for the first Nb prototype and the specification for FM coupler

Port for FM coupler  tuner  HOM coupler  superconducting junction
the superstructure will be fed by one coaxial coupler of the DESY TTF III type,
- the coupler will be placed 45 mm apart from the end cell (axial position),
  the radial position is changed because new beam tube has bigger radius by 18 mm,

- penetration depth of the antenna tip for $Q_L = 2.5 \cdot 10^6$ is $5 \div 6$ mm (similar to 9-cell cavities),

- the only modification is a new shape of the flange used for assembly in the cryostat (C. Martens).
The FM coupler specification for the beam test of Nb prototype (February / March 2001)

\[ I_{b, \text{max}} = 8 \text{mA}, \quad Q_L = 2.5 \cdot 10^6 \text{ (nominal value for TESLA 500)} \]

thus the operating voltage \( V \) (gradient \( E \)) and the beam power \( P_b \) are:

\[ V = (R/Q) \cdot Q_L \cdot I_b = 2928 \Omega \cdot 2.5 \cdot 10^6 \cdot I_b = 58.6 \text{ MV}, \]
\[ E = V/I_L = 58.6 \text{ MV} / (3.228 \text{ m}) = 18.2 \text{ MV/m}, \]
\[ P_b = V \cdot I_b = 468.8 \text{ kW}. \]

Expected total Lorentz detuning after 1300 \( \mu \text{s} \) at 18.2 MV/m will be about 200 Hz.
The total input power including power needed to compensate for the Lorentz detuning will be:

\[ P_{\text{in}} = P_b \cdot |1 + 0.25 \cdot (200\text{Hz}\cdot Q_l/f)^2| = 468.8\text{ kW} \cdot |1 + 0.037| = 486\text{ kW} \]
II. FM coupler for TESLA 500 and TESLA 800: Specification

TESLA 500, based on 4x7 cell superstructure:

\[ I_{b\text{ max}} = 9.5 \, \text{mA}, \quad V = 70.1 \, \text{MV/superstructure}, \quad E = 21.7 \, \text{MV/m} \]

\[ Q_L = 2.52 \times 10^6, \quad \Delta f = f/Q_L = 516 \, \text{Hz}, \]

\[ P_b = 9.5 \, \text{mA} \times 70.1 \, \text{MV} = 666 \, \text{kW}. \]

Expected Lorentz detuning \((k=1\,\text{Hz}/(\text{MV/m})^2)\) will be 300 Hz

\[ P_{\text{in}} = P_b \times [1 + 0.25 \times (300 \, \text{Hz}/\Delta f)^2] = 666 \, \text{kW} \times [1 + 0.085] = 723 \, \text{kW} \]
TESLA 800, based on 4x7 cell superstructure:

\[ I_{b \text{ max}} = 11.9 \text{ mA}, \quad V = 112.2 \text{ MV/superstructure}, \quad I_{\text{f}} = 34.7 \text{ MV/m} \]

\[ Q_L = 3.2 \cdot 10^6, \quad \Delta f = f/Q_L = 406 \text{ Hz}, \]

\[ P_b = 11.9 \text{ mA} \cdot 112.2 \text{ MV} = 1335 \text{ kW}. \]

Expected Lorentz detuning (\( k=1 \text{ Hz/(MV/m)}^2 \)) will be 768 Hz

\[ P_{\text{in}} = P_b \cdot |1 + 0.25 \cdot (768 \text{ Hz}/\Delta f)^2| = 1335 \text{ kW} \cdot |1 + 0.89| = \boxed{2529 \text{ kW}} \]
3rd Joint DESY – LAL – Saclay Workshop
on High Power Couplers for TESLA

LAL – Orsay, 17th and 18th January 2000

D. PROCH

(B. Dwersteg)
TESLA Waveguide Coupler

M.Dohlus, H. Hartwig, J.Boster, C.Martens, M.Seidel, A.Zavadsev

1. Versions, Geometrical Problems

2. Peak Field

3. Kick

4. Losses

5. Summary
Peak Field
S-Coupler

\[ \sqrt{4 \frac{w_E}{\varepsilon_0}} \geq \hat{E} \]
S-Coupler

\[
\sqrt{4 \frac{W_F}{\varepsilon_0}} \geq \hat{E}
\]

1.97 MV/m @ 1 MW input  2.78 MV/m @ 1 MW input

(scale: V/m @ 1W input power)
2L-Coupler

\[ \sqrt{4 \frac{\bar{w}_E}{\varepsilon_0}} \geq \hat{E} \]

Simulation model without curvature radius at extrusion

1.05 MV/m @ 1MW input power
2L-Coupler

$$\sqrt{4 \frac{\mathcal{W}_E}{\varepsilon_0}} \geq \hat{E}$$

801 kV/m @ 1MW input power
Kick
Coax-Coupler (9 cells, $Q_{\text{ext}} = 2.56 \cdot 10^6$)

$E_{\text{re}}$ max arrow = 39.9 MV/m @ 181 kW

$E_{\text{im}}$ max arrow = 0.44 MV/m @ 181 kW

transverse fields (on axis)

Martin Dohlus  Deutsches Elektronen Synchrotron  Jan.2000
Lorentz Force Coax-Coupler

(9 cells, $Q_{ext} = 2.56 \cdot 10^6$)

$$F_y(z) = \pm q \left( E_y(z) \pm c_0 B_x(z) \right) \exp \left( \pm \frac{j \omega}{c_0} (z - z_{cavity}) \right)$$

Integrated Kick

$$\int F_y(z) dz = q (-0.57 - j 0.77) \text{kV} \quad +v \quad /20 \text{MV} = (-28 - j 38) \ \mu \text{rad}$$

$$\int F_y(z)(-dz) = q (1.30 + j 1.43) \text{kV} \quad -v \quad /20 \text{MV} = (65 + j 72) \ \mu \text{rad}$$

@ $P_{in} = 181 \text{ kW}$
anti. symm. part of kick or
imag. part of kick voltage

\[
\text{Im}\left\{ \frac{V_{\text{kick}}}{V_{\text{acc}}} \right\} = T_x \sin \varphi_0 = 0.32 \text{ mrad sin}(157.7) \\
= 1.21 \times 10^{-4} \text{ rad}
\]

measured value
\[ Q_{\text{ext}} = 1.8 \times 10^6 \]

calculated value \( Q_{\text{ext}} = 2.6 \times 10^6 \)

\[
\text{Im}\left\{ \frac{V_{\text{kick}}}{V_{\text{acc}}} \right\} = \text{Im}\left\{ \frac{(1.3 + j1.4) \text{kV}}{20 \text{ MV}} \right\} = 0.72 \times 10^{-5}
\]

extrapolation \( Q_{\text{ext}} \rightarrow 1.8 \times 10^6 \) : 0.86 \times 10^{-5}
S-Coupler $Q_{ext} = 1.1 \cdot 10^6$

$E_{re}$ max arrow = 31.4 MV/m @ 800 kW

$E_{im}$ max arrow = 2.21 MV/m @ 800 kW

transverse fields (on axis)
Lorentz Force S-Coupler \( Q_{\text{ext}} = 1.1 \cdot 10^6 \)

\[
F_y(z) = \pm q \left( E_y(z) \pm c_0 B_x(z) \right) \exp \left( \pm \frac{j \omega}{c_0} (z - z_{\text{cavity}}) \right)
\]

Integrated Kick

\[
\int F_y(z)dz = q (16.0 - j 6.1) \text{ kV} \quad +v \quad /67.6 \text{MV} = (236-j90) \mu\text{rad}
\]

\[
\int F_y(z)(-dz) = q (18.5 - j 1.1) \text{ kV} \quad -v \quad /67.6 \text{MV} = (273-j16) \mu\text{rad}
\]

@ \( P_{\text{in}} = 800 \text{ kW} \)

Martin Dohlus  Deutsches Elektronen Synchrotron  Jan.2000
2L-Coupler

\[ Q_{\text{ext}} = 2.2 \times 10^6 \]

\[ E_{\text{re}} \text{ max arrow} = 47.6 \text{ MV/m} @ 800 \text{ kW} \]

\[ E_{\text{im}} \text{ max arrow} = 0.36 \text{ MV/m} @ 800 \text{ kW} \]

---

transverse fields (on axis)

---

Martin Dohlus  Deutsches Elektronen Synchrotron  Jan.2000
Lorentz Force  2L-Coupler

\[ F_y(z) = \pm q \left( E_y(z) \pm c_0 B_x(z) \right) \exp \left( \pm \frac{j \omega}{c_0} (z - z_{\text{cavity}}) \right) \]

Integrated Kick

\[ \int F_y(z) \, dz = q \left( -7.08 - j \cdot 4.69 \right) \text{kV} \quad +v \quad /67.6 \text{MV} = (-105-j70) \text{µrad} \]

\[ \int F_y(z)(-dz) = q \left( 3.33 - j \cdot 7.81 \right) \text{kV} \quad -v \quad /67.6 \text{MV} = (49-j115) \text{µrad} \]

@ \( P_{\text{in}} = 800 \text{ kW} \)
## S Coupler

<table>
<thead>
<tr>
<th>Klystron Operation</th>
<th>Configuration: steel: 2 mm @ waveguides 0.2 mm @ bellows copper: 5 μm (RRR=10)</th>
<th>Configuration: steel: 2 mm @ waveguides 0.2 mm @ bellows copper: 10 μm (RRR=10)</th>
</tr>
</thead>
</table>
| $P = 0 \text{ W}$  | $P_{2K} = 0.071 \text{ W}$  
$P_{4K} = 0.53 \text{ W}$  
$P_{70K} = 2.29 \text{ W}$  
$P_{300K} = -2.9 \text{ W}$ | $P_{2K} = 0.093 \text{ W}$  
$P_{4K} = 0.86 \text{ W}$  
$P_{70K} = 2.89 \text{ W}$  
$P_{300K} = -3.8 \text{ W}$ |
| $P = 800 \text{ kW}$  
$t_{\text{klystron}} = 1.4 \text{ ms}$  
$f_{\text{rep}} = 5 \text{ Hz}$  
$(P_{\text{av}} = 5.6 \text{ kW})$ | $P_{2K} = 0.149 \text{ W}$  
$P_{4K} = 1.48 \text{ W}$  
$P_{70K} = 4.09 \text{ W} + 2.96 \text{ W}^{(1)}$  
$P_{300K} = -0.02 \text{ W}$ | $P_{2K} = 0.165 \text{ W}$  
$P_{4K} = 1.79 \text{ W}$  
$P_{70K} = 4.73 \text{ W} + 2.96 \text{ W}^{(1)}$  
$P_{300K} = -1.0 \text{ W}$ |
| $P = 1.4 \text{ MW}$  
$t_{\text{klystron}} = 1.4 \text{ ms}$  
$f_{\text{rep}} = 5 \text{ Hz}$  
$(P_{\text{av}} = 9.8 \text{ kW})$ | $P_{2K} = 0.208 \text{ W}$  
$P_{4K} = 2.26 \text{ W}$  
$P_{70K} = 5.58 \text{ W} + 5.20 \text{ W}^{(1)}$  
$P_{300K} = 2.25 \text{ W}$ | $P_{2K} = 0.219 \text{ W}$  
$P_{4K} = 2.53 \text{ W}$  
$P_{70K} = 6.26 \text{ W} + 5.20 \text{ W}^{(1)}$  
$P_{300K} = 1.24 \text{ W}$ |

$^{(1)}$ dielectric losses (ceramic $\tan\delta = 0.0003$)
2L-Coupler  Normalized RF-Losses for $T = \text{const}$, $\kappa = \text{const}$

(without dielectric losses)

Martin Dohlus  Deutsches Elektronen Synchrotron  Jan.2000
material: 2 mm steel
copper plated

copper: **conventional copper** or RRR=10 copper

5 μm or 10 μm plating

bellows:

0.2 mm steel
copper plated

\[ h = 1.215 \times w \]

\[ w = 8 \]

\[ 40 \]

effective length = 3 \times \text{real length}

ceramic:

**DEVELOPMENT OF A HIGH POWER RF-WINDOW AT S-BAND**

H. Matsumoto
KEK, High Energy Accelerator Research Organization
1-1 Oho, Tsukuba, Ibaraki 305, Japan

Table 3: Physical properties of high-purity alumina ceramic.

<table>
<thead>
<tr>
<th></th>
<th>99.5%</th>
<th>99.9%</th>
<th>99.9% (no MgO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cal/cm-h-C</td>
<td>0.060</td>
<td>0.070</td>
<td>0.075</td>
</tr>
<tr>
<td>tan ( \delta \times 10^7 )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(at 2853 MHz)</td>
<td>13.0</td>
<td>3.0</td>
<td>0.27</td>
</tr>
<tr>
<td>(at 10 GHz)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Martin Dohls  Deutsches Elektronen Synchrotron  Jan.2000
## 2L Coupler

<table>
<thead>
<tr>
<th>Klystron Operation</th>
<th>Configuration: steel: 2 mm @ waveguides 0.2 mm @ bellows copper: 5 μm (conventional)</th>
<th>Configuration: steel: 2 mm @ waveguides 0.2 mm @ bellows copper: 10 μm (RRR=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P = 0 \text{ W}$</td>
<td>$P_{2K} = 0.139 \text{ W}$</td>
<td>$P_{2K} = 0.093 \text{ W}$</td>
</tr>
<tr>
<td>$(P_{av} = 0 \text{ W})$</td>
<td>$P_{4K} = 0.78 \text{ W}$</td>
<td>$P_{4K} = 0.83 \text{ W}$</td>
</tr>
<tr>
<td></td>
<td>$P_{70K} = 1.78 \text{ W}$</td>
<td>$P_{70K} = 2.79 \text{ W}$</td>
</tr>
<tr>
<td></td>
<td>$P_{300K} = -2.7 \text{ W}$</td>
<td>$P_{300K} = -3.7 \text{ W}$</td>
</tr>
<tr>
<td>$P = 800 \text{ kW}$</td>
<td>$P_{2K} = 0.154 \text{ W}$</td>
<td>$P_{2K} = 0.127 \text{ W}$</td>
</tr>
<tr>
<td>$t_{klystron} = 1.4 \text{ ms}$</td>
<td>$P_{4K} = 1.27 \text{ W}$</td>
<td>$P_{4K} = 1.81 \text{ W}$</td>
</tr>
<tr>
<td>$f_{rep} = 5 \text{ Hz}$</td>
<td>$P_{70K} = 2.87 \text{ W} + 2.96 \text{ W}^{(1)}$</td>
<td>$P_{70K} = 4.04 \text{ W} + 2.96 \text{ W}^{(1)}$</td>
</tr>
<tr>
<td>$(P_{av} = 5.6 \text{ kW})$</td>
<td>$P_{300K} = 0.6 \text{ W}$</td>
<td>$P_{300K} = -0.5 \text{ W}$</td>
</tr>
<tr>
<td>$P = 1.4 \text{ MW}$</td>
<td>$P_{2K} = 0.165 \text{ W}$</td>
<td>$P_{2K} = 0.153 \text{ W}$</td>
</tr>
<tr>
<td>$t_{klystron} = 1.4 \text{ ms}$</td>
<td>$P_{4K} = 1.74 \text{ W}$</td>
<td>$P_{4K} = 2.67 \text{ W}$</td>
</tr>
<tr>
<td>$f_{rep} = 5 \text{ Hz}$</td>
<td>$P_{70K} = 3.77 \text{ W} + 5.20 \text{ W}^{(1)}$</td>
<td>$P_{70K} = 5.08 \text{ W} + 5.20 \text{ W}^{(1)}$</td>
</tr>
<tr>
<td>$(P_{av} = 9.8 \text{ kW})$</td>
<td>$P_{300K} = 8.9 \text{ W}$</td>
<td>$P_{300K} = 2.1 \text{ W}$</td>
</tr>
</tbody>
</table>

$^{(1)}$ dielectric losses (ceramic tan$\delta = 0.0003$)
<table>
<thead>
<tr>
<th>S-Coupler</th>
<th>2L-Coupler</th>
</tr>
</thead>
<tbody>
<tr>
<td>length to flange critical</td>
<td></td>
</tr>
<tr>
<td>position of elliptical waveguide critical</td>
<td></td>
</tr>
<tr>
<td>≈ 1 MV/m</td>
<td></td>
</tr>
<tr>
<td>peak field (at 1 MW)</td>
<td></td>
</tr>
<tr>
<td>2.8 MV/m</td>
<td></td>
</tr>
<tr>
<td>kick (at 0.8 MW)</td>
<td></td>
</tr>
<tr>
<td>(18.5 - j1.1) kV</td>
<td></td>
</tr>
<tr>
<td>( \mu \text{rad} = \frac{67.6 \text{ MV}}{273.16} )</td>
<td></td>
</tr>
<tr>
<td>Losses (at 4k)</td>
<td></td>
</tr>
<tr>
<td>1.5 W @ 0.8 MW</td>
<td></td>
</tr>
<tr>
<td>1.7 W @ 1.4 MW</td>
<td></td>
</tr>
<tr>
<td>1.3 W @ 0.8 MW</td>
<td></td>
</tr>
<tr>
<td>2.3 W @ 1.4 MW</td>
<td></td>
</tr>
</tbody>
</table>
Rectangular Waveguide Input Coupler for Superstructure

A. Zavadtsev
DESY

Main parameters of the input coupler for superstructure

1. The input coupler consists of
   - the coupling element disposed in the cryomodule at 2K temperature.
   - the cold ceramic window at 70K temperature.
   - the warm ceramic window disposed out the cryomodule at room temperature
   - connecting line pieces with two bellows.

2. The input coupler is connected to the gas filled waveguide from the klystron.

3. The ceramic of the cold window should not be seen from the beam axis to minimize additional possibility of the electron emission from the ceramic.

4. There are two rectangular waveguide bellows both sides the cold window. Two rectangular waveguide bellow manufacturers are known at least:
   - Senior Flexonics Division Calorstat, France;
   - American Boa Cummings, USA.

5. The needed 21.7 MV/m gradient in 28-cell superstructure and 11.3 mA pulse beam current lead to the values: \( Q_{ext} = 2.12 \times 10^6 \) and RF power 792 kW.

6. Operating frequency 1.3 MHz.

7. 165.1x82.55 mm waveguide cross-section
* corresponds to middle case between two cases:
- r=0 and E=0 in the center of the ceramic (403 in this case).
- r=∞ and E=0 in the center of the ceramic (323 in this case).

To vacuum system

To Warm window
and RF-generator

Waveguide

Bellow

$90^\circ$ waveguide bend

Coupling element

Cryomodule

Beam pipe

Superstructure
Coupling element

L = 204 mm
H = 80 mm
\( Q_{\text{ext}} = 2 \times 10^5 \)
\( dQ_{\text{ext}}/dL = 1 \times 10^5 \text{ mm}^{-1} \)
\( dQ/dh = 2 \times 10^4 \text{ mm}^{-1} \)
♦ Frequency $f=1.3$ GHz.
♦ Ceramic: $\varepsilon=9$, thickness $t=9.84$ mm.
♦ Main mode $TE_{111}$ (in cylindrical cavity).
♦ Main component of electric field on the ceramic surface is tangential.
♦ $|S_{11}| \leq 0.05$ at $t=9.84$ mm in range $f=1286-1313$ MHz.
♦ $|S_{11}| < 0.1$ at $t=9.84$ mm in range $f=1264-1323$ MHz.
♦ $|S_{11}| \leq 0.05$ at the $f=1.3$ GHz in range $t=9.4-10.1$ mm.
♦ $|S_{11}| < 0.1$ at the $f=1.3$ GHz in range $t=9.1-10.3$ mm.
♦ Maximum electric field on the ceramic is 1.7 of maximum electric field in the waveguide.
Mag E

9.2186e+05
8.2967e+05
7.3749e+05
6.4530e+05
5.5312e+05
4.6093e+05
3.6874e+05
2.7656e+05
1.8437e+05
9.2186e+04
4.2737e-10
<table>
<thead>
<tr>
<th>Mag E</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.4777e+05</td>
</tr>
<tr>
<td>7.6299e+05</td>
</tr>
<tr>
<td>6.7821e+05</td>
</tr>
<tr>
<td>5.9344e+05</td>
</tr>
<tr>
<td>5.0866e+05</td>
</tr>
<tr>
<td>4.2388e+05</td>
</tr>
<tr>
<td>3.3911e+05</td>
</tr>
<tr>
<td>2.5433e+05</td>
</tr>
<tr>
<td>1.6956e+05</td>
</tr>
<tr>
<td>8.4779e+04</td>
</tr>
<tr>
<td>2.8642e+00</td>
</tr>
<tr>
<td>Mag E</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>5.9486e+05</td>
</tr>
<tr>
<td>5.3537e+05</td>
</tr>
<tr>
<td>4.7589e+05</td>
</tr>
<tr>
<td>4.1640e+05</td>
</tr>
<tr>
<td>3.5692e+05</td>
</tr>
<tr>
<td>2.9743e+05</td>
</tr>
<tr>
<td>2.3794e+05</td>
</tr>
<tr>
<td>1.7846e+05</td>
</tr>
<tr>
<td>1.1897e+05</td>
</tr>
<tr>
<td>5.9486e+04</td>
</tr>
<tr>
<td>2.8665e-10</td>
</tr>
</tbody>
</table>
Waveguide coupler with two bellows

Coordinates
X = 1.3
Y = 0.0102914
LOW LEVEL MEASUREMENTS ON REDUCED HEIGHT WAVEGUIDE TRANSITION

P. Lepercq, T. Garvey, R. Panvier
CNRS, IN2P3, LAL Orsay (France)

C. Travier, S. Chel, M. Desmons
CEA Saclay (France)
DESIGN OF THE NEW RF TRANSITION

- transition working under neutral gas pressure
- integration of the «hot» ceramic window in the design of the transition
- low electric field in the transition and the ceramic window
- large mechanical tolerances
- realisation easy
EFFECT OF SHIFT IN DIMENSIONS

Penetration of the reduced waveguide

Localisation of the reduced waveguide

Variation of the localisation of the short-circuit
LAL General Mechanical Design for TTF/TESLA Couplers

- to be first mounted in the 7th and 8th cryomodule?
- we need the confirmation of some tests (transition)
- Assumptions:
  - 3rd generation cryostat (± 2 mm)
  - stub tuner on the wave guide before the coupler (no adjustable antenna)
LAL General Mechanical Design for TTF/TESLA Couplers

- « Reduced Height Waveguide » transition (P. Lepercq)
  - SF6 / AIR
    - no vacuum, cost less money
  - welded core and guide
  - cost reduction (2500 $ with ceramic)
  - to be tested!
LAL General Mechanical Design for TTF/TESLA Couplers

- Ceramics brazed on titanium collar
  - easiest way to be made
  - less dielectric losses expected
  - Ti/SS transitions made by brazing
  - transitions welded (Ti/Ti & SS/SS)
  - exception: inner collar of cold ceramic: Copper
LAL General Mechanical Design for TTF/TESLA Couplers

- **Coax**
  - optimised thickness
    - 0.2/0.5/0.2/0.1 mm + stiffening collars
    - made by grinding
  - rigid couplers
    - ± 2 mm in each direction
    - just 2 very small bellows
  - copper coating
    - 5 microns everywhere except for:
      - bellows (probably tolerable)
      - titanium (very difficult coating)
  - length
    - a little bit longer than current coupler?
LAL General Mechanical Design for TTF/TESLA Couplers

- Static losses (w)

<table>
<thead>
<tr>
<th></th>
<th>LAL</th>
<th>Ferm.</th>
<th>DESY</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 K</td>
<td>0.035</td>
<td>0.03</td>
<td>0.051</td>
</tr>
<tr>
<td>4.2 K</td>
<td>0.42</td>
<td>0.32</td>
<td>0.39</td>
</tr>
<tr>
<td>77 K</td>
<td>0.48</td>
<td>2.2</td>
<td>1.65</td>
</tr>
<tr>
<td>RT</td>
<td>140</td>
<td>135</td>
<td>160</td>
</tr>
</tbody>
</table>

- RT = 800*L2 + 250*L4 +14*L77
LAL General Mechanical Design for TTF/TESLA Couplers

- Coax (II)
  - rigid connection between cryostat and waveguide
    - to protect the warm ceramic
  - closing
    - compensation of clearance by welded flanges
LAL General Mechanical Design for TTF/TESLA Couplers

- Cold ceramic
  - 3 options
    - TW
    - Cylindrical type (Desy type)
    - $\lambda/2$ (or twin-disk)

- Connection to cavity
  - 61.6 mm diameter?
Discussion of the Proposed Orsay-Saclay Coupler Design

T. Garvey (LAL, Orsay)

The French design is based on the following two assumptions (already discussed at the previous meeting):

(a) No variation is required on the antenna depth of penetration ($Q_{ext}$ variations are assumed to be done with a 3-stub tuner in the upstream waveguide).
(b) The longitudinal motion due to thermal shrinkage is $< \pm 1$ mm.

These assumptions were accepted.

The following comments were made:
· the stainless bellows must be coated,
· the overall coupler length is not necessarily fixed by the case of TTF,
· some mechanical flexibility is needed between the warm window and the WG transition,
· calculations are needed to check what we gain in going to 0.1 mm co-ax tube width,
· welding the warm part of the coupler to the cryostat is acceptable,
· we need to look seriously at how the coupler is mounted to the module,
· it was pointed out that the superstructure flange is intended to be $\phi = 80$ mm and not 60 mm.

→ Options for the French group:

(i) Design $\phi 80$ version of existing proposal,
(ii) Stay with $\phi 60$ and employ a « taper »,
(iii) Propose 60 mm flange for Superstructure and design ‘intermediate’ stage coupler (480 kW coupler, see transparencies of Sekutowicz).
**TF Linac ACC1 (Module 3) Input Couplers Performance.**


1. **Couplers Conditioning.**

<table>
<thead>
<tr>
<th>Total test time: 342hr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF ON time: 245hr. (72% of total time).</td>
</tr>
<tr>
<td>RF OFF time: 97hr. (Open tunnel time 24hr.).</td>
</tr>
</tbody>
</table>

   **Performance:**

   Test conditions: TW regime, On Resonance (with tuned cavities).
   - Power was limited by Klystron (~380kW max. per coupler).
   - Power rise time limited by coupler vacuum (2.5x10^-7 mbar max.),
     also e^- at long pulses (≥300μs) and several minor problems.
   - Electron pick-ups (e^- sensors) signal was in range of 0.5÷1.5V,
     (1.5V corresponds ~300μA).
   - Rise time (only RF ON) for rectangular pulses at 1Hz rep.rate:

<table>
<thead>
<tr>
<th>Pulse</th>
<th>20μs</th>
<th>20μs</th>
<th>50μs</th>
<th>100μs</th>
<th>200μs</th>
</tr>
</thead>
<tbody>
<tr>
<td>P_{for,max} ,kW</td>
<td>250</td>
<td>380</td>
<td>380</td>
<td>380</td>
<td>380</td>
</tr>
<tr>
<td>time, hr</td>
<td>11</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pulse</th>
<th>300μs</th>
<th>300μs</th>
<th>400μs</th>
<th>500μs</th>
</tr>
</thead>
<tbody>
<tr>
<td>P_{for,max} ,kW</td>
<td>250</td>
<td>350</td>
<td>300</td>
<td>260</td>
</tr>
<tr>
<td>time, hr</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

   - Rise time (only RF ON) for rectangular pulses at 10Hz rep.rate:

<table>
<thead>
<tr>
<th>Pulse</th>
<th>20μs</th>
<th>50μs</th>
<th>100μs</th>
<th>200μs</th>
<th>200μs</th>
</tr>
</thead>
<tbody>
<tr>
<td>P_{for,max} ,kW</td>
<td>360</td>
<td>360</td>
<td>360</td>
<td>300</td>
<td>340</td>
</tr>
<tr>
<td>time, hr</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

   - Rise time (only RF ON) for FT pulses at 10Hz rep.rate:

<table>
<thead>
<tr>
<th>Pulse</th>
<th>240μs</th>
<th>440μs</th>
<th>440μs</th>
<th>640μs</th>
<th>1040μs</th>
<th>1200μs</th>
</tr>
</thead>
<tbody>
<tr>
<td>P_{for,max} ,kW</td>
<td>350</td>
<td>250</td>
<td>350</td>
<td>350</td>
<td>340</td>
<td>350</td>
</tr>
<tr>
<td>time, hr</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>0.5</td>
<td>2</td>
<td>2^*</td>
</tr>
</tbody>
</table>

   * with bias voltage 2.5kV on.

   **Main Problems:**

   a. 1 Hz repetition rate.
   - Klystron IL events.
   - VAC.Cpl and e^- IL events.
   - Spark, PM, WG Spark IL events caused by X-Rays.

   b. 10Hz Repetition rate.
   - Klystron and Modulator IL events.
   - Klystron Gun Voltage jumps.
   - VAC.Cpl IL events.
   - Cavity 8 Quench (3 times, at FT 240+800μs, 10dB, 350kW)
   - Coupler 2 behavior at high gradient. Knob heated up (ΔT_{max}=+30K).
   It looks like thermal flow goes from center of coaxial part.
Fig. 1. TTF Module layout.

Power rise time (RF ON time) for rectangular pulses at 1Hz repetition rate.

Fig. 2. TTF Module Input couplers performance.
2. **Single Cavities tests.**

TESLA resonators were tested. Maximum $E_{acc}$ was determined for each cavity. Cryo losses measurements were done. Maximum accelerating gradient was obtained in region of 18-30MV/m limited by thermal breakdown in cavities, no limitation from couplers performance was present.

Main Problems:
- Klystron Gun Voltage jumps.
- RF Loop operation is too noisy.
- Coupler 2 behavior at high gradient. VAC.Cpl IL events.
- Klystron IL events.

3. **Module test.**

Power was connected to all cavities normal way save cavities 1 and 8, because they have lower maximum $E_{acc}$ values.
Cavity 1 has 1.1dB and Cavity 8 has 3.0dB attenuation in WG.

Operating at FT pulse, 1300μs, $P_{t_{\text{max}}}=185kW$
Maximum non-stop time: 11 hr.
Maxime time without the Quench: 22 hr.

Electron sensors still registering some activity (0.2-1.5V)
On coupler #3 e- pick-up voltage holds on 1.0V (~200μA) level.
Coupler #2 knob $\Delta_{\text{max}}=+7K$.
Couplers Vacuum level dropped from $2 \times 10^{-7}$ to $2 \times 10^{-9}$mbar within 72hr.

Main Problems:
- Klystron Gun Voltage jumps (with 3.0-6.5kV amplitude).
- Klystron Modulator IL events (12.11-14.11 → 17 events)

4. **Module test (continuation).**

$E_{acc}=22\pm1$ MV/m reached with beam.

Main Problem:
Coupler #3 $Q_{ext}$ dropped drastically, no operation was possible.
Coupler Vacuum jumped up to IL level, 3 e- pick-up filters were destroyed.
HV input impedance measured was 18MΩ (must be infinite).
Probably, that was caused by plasma discharge in warm coaxial part.
After disconnecting HV and shortening of HV input problem disappeared.
Exact cause of this can by discovered by disassembling.

5. **Conclusion.**

TTF Linac module #3 operation allowed its multiplicity of different systems and parts to be tested in order to determine the performance of superconducting linac module as a whole. As a primary goal of this test superconductive TESLA cavities performance investigation should be named, but many other systems must be put under test as well. TESLA main couplers are one of such parts. Performed test operation showed that TESLA couplers apt to meet needed requirements for linac operation and the main limitation of accelerating gradient increasing are resonators themselves. Minor problems accounted with TESLA couplers are nevertheless important to be investigated and could be solved by gaining more experience on this way.
Experiences and problems in designing and manufacturing coaxial couplers

by Cornelius Martens, DESY

Introduction
- the coaxial concept, warm window
- prefer welding instead of brazing (so copper-plating is necessary)

Machining and cleaning cylindrical Parts
- machining cylindrical parts
- cleaning and transport

Welding and Brazing
- welding
- heat procedure
- brazing copper-rings and 4.5K-connector

Copper-plating
- inner and outer conductors
- cleaning and package
- What's not to cover?
- Standard-procedure for copper-plating

Manufacturing ceramic windows
- manufacturing and accuracy
- material
- metallisation
- brazing
- TiN-coating
- EB-Welding
- Standard-procedure for ceramic-handling

- Some points for handling and mounting UHV-components
Introduction

- all manufactured couplers for TTF are coaxial.
- difference between copplerII and III is the warm window under atmospheric conditions (two instead of three vacuum components).
- coaxial line is welded and copper coated

Machining and cleaning

- machining without problems
- cleaning (washing-machine) and washing in clean, destilled water.
- natural surfaces prepared with a special liquidity to avoid oxidates („Passivierung“).

Example: Waveguide windows after acid-procedure. Spots or dirt is visible after acid procedure and heating. Reason is not clear at time.
Welding and brazing

- no problems with welding cylindrical parts.
- leack-test after every step.
- cleaning with destillated water (washing-machine) and next
- heatet-procedure at 800°C for 1h for stainless-steel (before coating!)
- transport and rest in transport-vessels for each assembly or in special paper (no dust or fluff-paper). Avoid polymere-packages!
  - Example 1: Inner and outer conductor
  - Example 2: welding waveguide for coupler.
- solder-Part: copper-ring at cold side flange without coating.
  - Example 4: 4.5K connecter. Cu-ring was not correctly positioned at brazing.
großser Flansch
Mühl-Krögen
3,96 4728/A, 300

(5')

Kern-Lotkopfendbund

Spleißerstellen: Leim. Einbringung Rest von Lot
Leim des C-Krögen mit C-5 Fuller bis 1020°C im Vakuum
**Standard procedure for Copper-plating**

- All parts and welded assemblies have to be clean. There shouldn’t be lubricants on the surface.
- The last cleaning should be done with distilled water.
- Heat the parts at 950°C for two hours (stainless steel, the material for flanges can be 1.4429)
- The triple R should be defined by the customer.
- Tolerances for copper plated complex parts should be equal or higher than ±30% (for a thickness between 10 and 40μ). For example inner conductor with bellow: 10μ±3μ. Higher accuracy is not reachable.
- The regions of seals (Cy-Flange) shouldn’t be coated.
- Edges of CF-flanges shouldn’t be coated.
- Threads (for screws) shouldn’t be coated.
- No interesting surfaces (outer surface of an outer conductor) needn’t be coated but they can! This minimizes costs.
- These points should be remarked in the drawings.
Manufacturing ceramic windows

- manufacturing is done by WESGO Ceramics GmbH/Germany
- cold pressing of material and heating under melting-point (1700°C).
- material is Al300 (not pure Al₂O₃, bad quality of metallisation ⇒ share of glas-matrix).
- surfaces are smoothed.
- accuracy of ceramic procedure: ±1% is reachable.
- ceramics are metallised in the ground of the left- and rightside gaps. (Mo-Mn-film, then Ni-coatet). This metallisation has to be soldable.
- The metallized ceramic is heated at 800°C (or higher) for one hour.

Problem: grey spots on ceramic-surface

- brazing copper-rings at 780°C with Silver-Copper Alloy (AgCu28).

Ceramic should be covered.

Example 1: in the past: dirty stove at desy (DESY bought a new one).

Example 2: bellows with less inner dimension.

- titanisation in two steps (thickness of 100A). The welding area should be covered.

- Standard procedure for ceramic-handling.
Durchmessermasse beziehen sich auf den Schnitt der Geraden

UHV-gerecht verpackt. Keine Polymerverpackung verwenden

Handhabung nur mit Balsit-Handschuhen und füsselfreien Balsit-Tuechern

DIN 150 W15
DESY-Haar

Der Gesamtdruck wird erreicht durch:

1. Gasdruck
2. Oberflächenenergie

Massstab 1:8
bis zum Formansatz hartlochlebig metallisirt

70 K-Fenster
für '11F-Koppler II

Werkstoff: Al 300 (Fa. Wesgo)

DESY-MHF
3 96 4328/A.201

Name:...
Datum:...
1. Keramik hartlötelfähig metallisiert bestellen.

2. Keramik bei 800°C 1 Std in sauberem Vakuum (p<10⁻⁵ mbar) entgasen, danach Handhabung nur noch mit Handschuhen und fusselfreien Batist-Tuechern. (UVV-Richtlinien Beachten)

3. Loeten der Keramik bei 780°C mit Cu-Ag-Eut. im Vakuum, dabei Keramikoberflächen innen und aussen mit Keramikrohren abgedeckt. (Lotueberschuss darf nicht Cu-Kragen ausserhalb der Keramik netzen)

4. Aufdampfen einer TiN-Beschichtung aussen und innen von 100 Ångstrom, (sollen sichtbar ein wenig gelblich sein) (Schweisskante 3mm abdecken) danach bei 350°C 1 Std tempern, mit trockenem N₂ fluten.

**Standard procedure for ceramic-handling**

- Not every ceramic material is usable for metallisation. A shared glass-component in the matrix is needed (e.g. Al300 WESGO).
- All ceramic parts should be clean. Ceramics shouldn’t be touched. Or if necessary only with clean gloves. Never touch the surface with fingers.
- Don’t wash or wipe the surface.
- The metallized ceramic will be heated at 800°C for one hour. The heat-procedure should be the last cleaning-step.
- Cover the ceramic-surface if brazing.
- After brazing (Ag-Cu-Alloy, 780°C) heat the ceramic at 350°C for one hour.
- Transport and rest only in vessels or packed in special paper (no fluff/dust paper). Rest in Nitrogen is usual.
**EB-welding**

- EB-welding is done by ACCEL/Germany
- antennae is covered with titanium-sheets
- shrinking between 0.2 and 0.4mm for each ring
Copper-plating

- coating is done by Collini-Flühmann AG/Switzerland.
- vacuum-assemblies cleaned and heated in vacuum at 950°C for 2 hours
- reachable accuracy of tickness: ±30% for complex structure (e.g. bellows)
- thickness of inner conductor from 27 to 45μ
- thickness of outer conductor from 7 to 13μ (current is lower).
- cleaning with destilled water, drying in Nitrogen-atmosphere
  - Example 1: bellow with leack after Copper-plating
- transport in vessels for each assembly (avoid damages!)
  - Example 2: holder of Cu-antenna.
- no directly touch is allowed! handling only with gloves
- defining the metallized surfaces is important.

Examples: regions of seals (Cy-flange), edges for CF-flanges, threads. Outer surfaces needn't be coated but they can!

- Standard-procedure for Copper-plating.
Results from the Travelling Wave Window tests

C. Travier (CEA Saclay)

Outline

- Travelling wave window design
- Low level RF measurements
- Power test stand
- RF conditioning
- First power cycling
- Steady state TW operation

This talk is based on the publication « Design and test of a 1.3 GHz Travelling Wave Window » made at the Santa Fe SRF workshop.
Travelling Wave window design

- Concept first proposed by Kasakov (1992)
- First application to coaxial window for Tesla coupler by Mosnier & Hanus (1995)

Principle
Establish a pure travelling wave inside the ceramic

How to achieve it
Use matching inductive or capacitive components on both sides

![Matching iris](image)

Avantage
- Reduces Electric field inside the ceramic
- Allow to use a thin ceramic (reduces dielectric losses)
Present Travelling Wave window design

Advantages

- low field at brazing point (25% of coax inner conductor field)
- low dielectric loss (17 W @ 1 MW-1% duty cycle)
- great flexibility in parameters choice
- potentially moderate cost for large number
- no multipactor
- no direct view of cavity electrons
- large diameter (150 mm)
- high field on noses (2 times coax inner conductor field)
- difficult to clean
- narrow bandwidth (60 MHz @ 20 dB)

Drawbacks
Mechanical design

2 windows were fabricated by SICN
- both, with copper inner conductor
- one with copper outer conductor
- one with titanium outer conductor

- Al300 (97.5 %) from WESGO was used
Low level RF measurements

$\varepsilon = 9.5$ is deduced from $\lambda/2$ window measurements

*Larger discrepancy between measured and computed curve for copper window is due to less precise dimensions measurement*

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**Figure 1:**
- Solid line: Superfish simulation of actual geometry for Ti TW window
- Dashed line: Low level RF measurements Ti TW window
Travelling wave window

copper
titanium
Conditioning procedure

Fixed parameter: Pulse length 0.8 ms

Power = 0

More

Less

Apply Power

10^{-5} \text{ mbar}

Hardware interlock
e- and light are fast interlocks (5 \mu s)
vacuum is slow interlock: next pulse

More

Less

\text{e- threshold: } 5 \text{ mA}
\text{Light threshold: } 10^8 \text{ photons}
\text{Vacuum threshold: } 10^{-5} \text{ mbar}

Operator defined

Less

Good pulse = good pulse + 1

Less

Ngood (2)

Operator defined

Less

Outgassing 10^{-7} \text{ mbar}

Operator defined

More

P_{\text{max}}

Increase power by one step

Start over the ramping between 0 and P_{\text{max}}

Operator defined

After a few ramping, P_{\text{max}} is increased, until one reaches 1 \text{ MW}
Test stand

- Ion pump
- Transmitted RF power
- Waveguide window
- Load or short
- TW window
- Incident & reflected RF power
- Klystron
- Cryostat
- PM1
- PU1
- PU2
- PM2
Cryostat

window to test

inside view
## Operating sequence

<table>
<thead>
<tr>
<th>Number of pulses</th>
<th>Power level (kW)</th>
<th>Temperature (K)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Travelling wave operation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25,500</td>
<td>0-1000</td>
<td>230</td>
<td>conditioning</td>
</tr>
<tr>
<td>1,700</td>
<td>0-400</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>8,800</td>
<td>400-650</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>25,000</td>
<td>300-1000</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>26,000</td>
<td>500-1000</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td><strong>Standing wave operation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>44,400</td>
<td>0-1000</td>
<td>230</td>
<td></td>
</tr>
<tr>
<td>8,000</td>
<td>0-1000</td>
<td>230 →105</td>
<td>cooling</td>
</tr>
<tr>
<td>7,000</td>
<td>1000</td>
<td>105</td>
<td></td>
</tr>
<tr>
<td>26,000</td>
<td>0-1000</td>
<td>105</td>
<td></td>
</tr>
<tr>
<td>12,000</td>
<td>1000</td>
<td>105</td>
<td></td>
</tr>
<tr>
<td><strong>Interdigital wave operation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15,000</td>
<td>0-1000</td>
<td>105</td>
<td></td>
</tr>
<tr>
<td>4,000</td>
<td>100</td>
<td>175</td>
<td>Window baking</td>
</tr>
<tr>
<td>21,000</td>
<td>0-1000</td>
<td>105</td>
<td></td>
</tr>
<tr>
<td>9,000</td>
<td>1000</td>
<td>105</td>
<td>Losses measure</td>
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<tr>
<td>13,000</td>
<td>0-1000</td>
<td>105</td>
<td></td>
</tr>
<tr>
<td>27,000</td>
<td>0-1000</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>18,000</td>
<td>1000</td>
<td>250 →300</td>
<td></td>
</tr>
<tr>
<td>42,000</td>
<td>0-1000</td>
<td>300</td>
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</tr>
<tr>
<td>33,000</td>
<td>500-1000</td>
<td>105</td>
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<td>74,000</td>
<td>0-1000</td>
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<td>8,000</td>
<td>1000</td>
<td>300</td>
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</tr>
<tr>
<td>28,000</td>
<td>700-800</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>9,000</td>
<td>1000</td>
<td>300</td>
<td></td>
</tr>
</tbody>
</table>
Conditioning

1 MW was reached after 21,000 pulses

This corresponds to 58 hours @ 0.1 Hz and 6 hours @ 1 Hz
Signals during conditioning

Vacuum

Light

Electrons
Signals during conditioning (vs. Power)

Upstream

Light

Upstream photomultiplier (V)

Power (kW)

Doorknob transition

Coax

Downstream

Upstream electron PU (V)

Power (kW)

first ramping only

Coax

Electrons

Downstream electron PU (V)

Power (kW)

Coax or window?
Signals during first complete power ramping (vs. Power)

**Upstream**

**Light**

![Graph of Light vs. Power](image)

*The smooth signal has been subtracted*

**Vacuum**

![Graph of Vacuum vs. Power](image)

**Downstream**

**Light**

![Graph of Light vs. Power](image)

*Downstream light = 0*

**Electrons**

![Graph of Electrons vs. Power](image)

*Upstream e- = 0*

**Barriers found on vacuum signals**

<table>
<thead>
<tr>
<th>Power (kW)</th>
<th>Barriers found on PM signals (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>435</td>
<td>410</td>
</tr>
<tr>
<td>490</td>
<td>515</td>
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<tr>
<td>555</td>
<td>555</td>
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<td>585</td>
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<td>645</td>
<td>635</td>
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<td>705</td>
<td>715</td>
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<td>745</td>
<td>745</td>
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<td>860</td>
<td>860</td>
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<tr>
<td>940</td>
<td>960</td>
</tr>
<tr>
<td>1005</td>
<td>990</td>
</tr>
</tbody>
</table>
Steady state operation: conclusions

- operation in standing wave regime at high power helped the processing of the doorknob transition

- at the end, back to TW operation, only remains a very low upstream light signal

- on downstream side, the 700 kW coax multipactor barrier is still visible, but the corresponding outgassing is only $3 \times 10^{-9}$ mbar

- we didn’t observe any difference between operation at 100 and 300 K

- dielectric losses inside the ceramic are not measurable (20 mW with our duty cycle)
Argon Discharge Treatment of Input Couplers

D. Kostin, M. Lalayan, W.-D. Moeller, D. Proch, S. Yarigin, A.Zavadtsev

DESY

1. Present state of TTF 2 – type couplers

RF processing rate for different coupler pairs tests
(time needed for RF power reached target value on each pulse length)

Problem: Processing is too time-consuming.

Proposal: Use RF-driven discharge in Argon under controlled conditions to clean-up surface
2. Argon discharge treatment procedure

2.1. Ar-treatment place in the Main scheme

Vacuum pumping + baking at 200°C
Ar - process
Pumping
RF procedure on 20μs, 50μs ...

2.2. Modification of RF scheme for Ar-processing

To obtain uniform treatment of RF surfaces we made standing wave phase shift using:

a. Long RWG is connected to output coupler
b. Frequency sweeping 1.95 MHz

=> Standing wave phase within test stand shifted on $\lambda/2$

RF–scheme for RF–conditioning

Modified RF–scheme for Ar processing
2.3. **Algorithm**

A. Only input coupler filled with Ar at 10 mbar (slightly higher than Paschen curve minimum)
   - RF is on for ~1 hour
   - Exchange Ar with fresh one
   - RF is on for ~1 hour
   - Pump Ar out of input coupler

B. Only cavity filled with Ar at 10 mbar.
   - Procedure is the same

C. Only output coupler filled with Ar at 10 mbar.
   - Procedure is the same

![Diagram of RF, Input coupler, Output coupler, and Cavity]

2.4. **Diagnostics and handling soft discharge during Ar-process**

RF power control:

- Pulse length: 20 µs
- Repetition rate: 2 Hz
- RF power level: up to reflected power appeared

Sensors

- Light: switched off
- Electron pickups: Ar pressure is controlled manually
- Pressure
- P reflected
- P forward
- P transmitted
Comparison of typical input coupler test

and test after Ar treatment

Forward power vs. time

[Graph showing forward power vs. time for different coupler pair tests (DE6 DE7, DE8 DE9, DE11 DE10, DE12 DE13) with various pulse lengths indicated.]
3. **Modification of Argon Processing Algorithm**

**A. Sequence changing**

1. Vacuum pumping of **all volumes**
2. Fill with Ar at 10 mbar **output coupler** volume and do RF process
3. Ar pressure increasing in output coupler to 100 mbar
   - Fill with Ar at 10 mbar **cavity** volume and do RF process
4. Ar pressure increasing in cavity to 100 mbar
   - Fill with Ar at 10 mbar **input coupler** volume and do RF process
5. Final pumping out

---

*Paschen curve for Ar*

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![Paschen curve for Ar](image-url)
B. Ar processing at higher repetition rate (10-20 Hz)

Ar processing details

Coupler pair test
Improvement of Coupler Processing in Chechia and in Cryomodule

Frequency sweep during Ar and RF conditioning

Smith chart

- \( Q_0 = 5 \times 10^9 \)
- \( Q_{\text{ext}} = 3 \times 10^6 \)
- \( f_0 = 1.3 \text{ GHz} \)
- Frequency sweep 1 kHz

- Electric field maximum displacement in coupler is equal to \( \lambda / 2 \)
  (115 mm in coaxial line)
3rd Joint DESY – LAL – Saclay Workshop
on High Power Couplers for TESLA

LAL – Orsay, 17th and 18th January 2000

S. IARIGUINE
Control signals limits determination.

a. Vacuum

It is measured by current of ion-pumps.

IL value is $1 \times 10^{-5}$.

Soft limit is $2 \times 10^{-7}$.

This corresponds to the highest safe stable value, at higher values the probability of discharge increases rapidly (as of our experience with TTF couplers). It is possible to maintain power increasing if the vacuum is about this value (with our speed vacuum measurements and response in power). Probably it is possible to work at higher values, but only with faster response and measurements.

Currently response in power take 20-30s, it is a program cycle. At 2Hz repetition rate it means 40-60 pulses.

It is necessary to work at highest value as possible to achieve the highest speed of RF-cleaning.

Vacuum now is the main parameter of processing and clean state indicator.
b. Electron current

The pick-up antennas on the outer coax wall are used for DESY II coupler.

There are three places:
- warm part top (e-3),
- warm part bottom (e-2),
- could part (e-1).

All earlier tests were done with cards, which give 1V output at 500mkA, and have a saturation at about 1.8V.
The 30V voltage is applied to each pick-up.

Last measurements shows, that at pressure $2 \times 10^{-7}$ we have a current about 2mA. (card saturation at $1.86 \times 2\text{mA}$)

IL limit is at 3V. It corresponds to the 170mkA CW (180kOm). Card has some integration circuit, so it allow more amplitude at short pulses.

These old e-monitor card can not work with pulses less then 100mks, it makes unreliable output in this case and should be calibrated in a way, different from long pulses or CW.

At the last week new fast cards was tested, they have limit of 2mA at 1V scope output. IL integration constant was not yet calibrated. That cards can measure pulses shorter then 15mks.

It is possible to use whole inner-coaxial as e-pick-up, in this case the integral current will be seen, but it is difficult to apply at the same time HV.
During the process the next parameters are monitored:
Vacuum in each part of test-stand.
Electron current through e- pick-ups.
Light in RWG box of couplers.
Temperature of warm window (by IR).
Temperature of could window (by touch-thermometer at 80k flange).
Spark detector to indicate a brake-down on the air part of warm window.

There are two kinds of limitation for this parameters: program soft limits and hardware IL limits.
If IL limit is overcome for some of them then hardware will switch the power off completely.
If soft limit is overcome then control program will decrease the input power in some rate (typically 0.1..0.3 dB).

c. ML investigation procedure.
First clean coupler without HV and with 600mks pulse up to 1000kW, like in previous steps.
"Clean"-means that all control signals are below the soft limits, so there is no probability to receive problems in power region up to 1000kW.
Then at each HV value power goes from 10 to 1000kW and down two times (2 times sweep).
After all the signals are analyzed in order to obtain the ML regions for each HV value.
The Main processing sequence.

a. Baking

Normally backing is carried out after the assembly of coupler at test-stand and vacuum leak check.
Main purpose of it is to remove water and oil from surfaces.
The procedure is next:
1) increasing of temperature in 20C steps up to 200C.
1) Stay at 200C until the pressure in couplers start to goes down.
1) Step decreasing of temperature back.
Total time required is about 2 or 3 days. During the backing pumping is carried out by ion-pumps.
Pressure is maintained below $10^{-5}$ mbar in order to avoid Cu oxidation.

b. Pulse RF cleaning at travelling wave.

Purpose: Remove residual dirt and field emission sources.
The main sequence looks like it shown below.
All process goes at 2Hz repetition rate.
Procedure for each pulse length from 20, 50, 100, 200, 400 mks:
1) Power rise up to 1000kW.
1) Maintain power at 1000kW for some time
   (typically about 20min to 1h).
1) Power decreasing to about 10kW and switch to the higher pulse length.
Procedure for each pulse length from 800,1000,1300 mks:
1) Power rise up to 250kW.
1) Maintain power at 250kW for some time (about 20min to 1h).
1) Power decreasing to about 10kW and switch to the higher pulse length.
This sequence was applied as initial step for most of couplers in the last time.
Picture 1: Coupler diagnostic.
Test processing of TTF input couplers.

1. Preface
   At TTF we treat the coupler at 3 different places:
   1) 2 couplers test
   1) Horizontal test
   1) Module
   Here the first one will be observed\(^1\).

2. Couplers conditioning at 2-couplers test-stand.

   Goals in rough priority order.
   1) Check functionality of each coupler.
   1) Make the first high temperature and RF cleaning of each coupler.
   1) Investigation of multipucting with HV and without HV.
   1) Investigation of different control signals (e-, vacuum, light) during RF operation.

\(^1\) Not all couplers/cavities go through the horizontal test, the main points are the same for all tests. Horizontal test is similar to modul operation
c. Light

Light is measured at the RWB box of DESYII coupler. Card and photomultipliers are calibrated to see up to 1 lux light. IL limit is currently set to 0.5 lux. Soft limit is about 0.4 lux.

At some conditions it should be adjusted lower, in order to receive stable operation without IL's. These values roughly correspond to the vacuum ones. That is: if light is constantly at 0.4 lux, the vacuum should be in a region around $2 \times 10^{-7}$.

Light measurements are fast enough to see 10mks pulses. Because of glossy Cu surface, it is possible to detect light in whole warm part, but probably with different absolute value.

d. Temperature of windows.

Warm window temperature can be detected by IR sensor. Could window temperature is detected by temperature of outer conductor near the 80K flange. Which is not so precise.

The IL value is set to 40C. No any troubles were encountered with DESYII windows temperature. Because temperature measurements are very slow, they can not be effectively used for rapid power control during conditioning.

3. Some Conclusion.

1) We are not pleased with time of processing.
2) Our diagnostic is not perfect. only vacuum is more or less reliable.
3) Limitations for e- have improper settings now
4) Pressure limits can be set a little higher. $4 \times 10^{-7}$ mbar.
5) May be it will be good to implement some experience of CERN couplers processing to our side.
Coupler DE15/DE14 t1

Photo 3
SECOND LAMBDA/2 WINDOW PRELIMINARY RESULTS

C. Travier (CEA Saclay)
Lambda/2 windows

1) Differences between the 2 windows during fabrication

First Window:
- ceramic brazed onto Cu and Kovar collars
- TiN coating
- E-B welding of flanges

Second Window:
- TiN coating
- ceramic brazed onto Cu and Kovar collars
- E-B welding of flanges

2) Differences during conditioning

First Window:
- conditioning @ room temperature
- conditioning under SW regime
  - 30'000 pulses to reach 1 MW
  - than "dramatic event" that induces ceramic coating with copper
- 300'000 pulses to recondition to 1 MW

Second Window:
- conditioning @ 100 K
- conditioning under TW regime
  - 130'000 pulses to reach 1 MW
SECOND X/2 WINDOW: after \(~ 400,000\) pulses

**downstream light**

**upstream light**

**downstream e-**

**upstream e-**

\(\sim 450\text{ kWe}\)
\(\sim 560\text{ kWe}\)
\(\sim 580\text{ kWe}\)
\(\sim 700\text{ kWe}\)

\(\sim 350\text{ kWe}\)
\(\sim 430\text{ kWe}\)
\(\sim 550\text{ kWe}\)
\(\sim 950\text{ kWe}\)
SECOND $\frac{\lambda}{2}$ WINDOW after n 600 '000 pulses

$v1_{\text{max}}$ VS. $pd1_{\text{max}}$

$v3_{\text{max}}$ VS. $pd1_{\text{max}}$

$v1_{\text{max}}$ VS. $pd1_{\text{max}}$

$v3_{\text{max}}$ VS. $pd1_{\text{max}}$
LIGNE2  24/09/1999
PRF = 1200kW  800us  avec et sans lumière sur la fenêtre Thomson aval
27/09/1999  Ligne2
analyse de gaz sans électrons Pick-Up  (1200kW 800us)

sans HF  avec HF
27/09/1999     Ligne2
analyse de gaz avec électrons Pick-Up     (PRF = 500kW 800us)

□ sans HF  □ avec HF
Ligne2 7/10/1999
Traveling Wave 100kW à 1300kW

concentrations (%)

temps relatif (s)
Conditioning the couplers

- avoid the volumes difficult to pump,
- condition at high temperature (300°C), following the indications of the RGA,
- ventila at atmospheric pressure under dry nitrogen
- condition in situ with a bakeout at 120°C, following the RGA (H2O decreases)
- condition with the RF power on, under vacuum with a turbomolecular pump with a high compression rate,
- when the satisfactory pressure is obtained (1. 10-8 mbar), start the ion pumps

Preventive measures

- use a fast vacuum interlock (VAT) with a response time of a few ms (threshold at 1.10-7 mbar or less)
- use a visual detection of the emission light by camera.

Remarks

- there is a memory effect after a conditioning with bakeout and RF power
- ventilating under dry nitrogen and good conditions of cleanliness, allow to lose only 30% of the conditioning,
- at the ESRF, the vacuum interlock threshold is now at 5.10-8 mbar.
Multipactor calculations

G. Devanz, CEA/Saclay

TESLA Power Coupler Workshop
2D multipactor code

- Based on CAD-like geometry description
- Uses fish/cfish EM-fields
- Adaptative RK (4-5th order) integration

General purpose
- Accelerating cavities
- RF windows, both in TW & SW
- Other «2D» coupler parts (tapers, coaxial lines)
Milan 704 MHz a103

$E_z$ field

$E_r$ field

$H_\theta$ field
A 102 Cavity (circular)

2 MV/m

3 MV/m
A 103 Cavity (elliptical)

2 MV/m

5 MV/m
Secondary emission coefficient for Nb

- \( \delta \) after wet treatment
- \( \delta \) baked out at 300° C
- \( \delta \) after gas discharge, cleaned with Ar

\[ \delta \text{ after wet treatment} \]

\[ \delta \text{ baked out at 300° C} \]

\[ \delta \text{ after gas discharge, cleaned with Ar} \]

incident electron energy [eV]
Code testing

- Influence of $\delta_{\text{max}}$ of surface materials:
  changed from 1.5 to 1.1 $\Rightarrow$ almost no multipactor left
- SEE $\delta$ parameters need to be tuned for every material of the problem
- Slight discrepancy observed when using Superfish fields or analytical expression in the case of a coax line in TW mode: 10% error on power levels (relative field errors in Superfish can be kept as low as $10^{-4}$).
- Simple case of the 60 mm 50 $\Omega$ coaxial line
Test with the $\lambda/2$ geometry

TW mode: electrons follow the EM wave

greater $e^-$ activity expected on the upstream side in the vicinity of the ceramic
Comparison with experimental results

- Power levels OK for the highest $\epsilon^-$ yield barriers

MP barriers can be predicted with the average impact energy

- $\delta > 1$

$\delta$ values need some tuning...
Status & perspectives

- **Parallelization (in progress)**
  - On Networked workstations
  - PVM library (almost a standard now). Several architectures can be used in a single Parallel Virtual Machine
  - Computation parameters distributed over $N_{ws}$ machines, with load balancing. Speedup by a factor of $N_{ws}$

- **Simulation of the measurements (in progress)**
  - Define detector elements in the geometry (e.g. pickups)
  - Use Poisson static field map

- **Better description of the $e^- \rightarrow$ solid interaction**
Conclusion

• Need a better knowledge of surface condition
  • Simulations are VERY sensitive to $E_1$, $\delta(E1) = 1$ (SC cavities)
  • SEE $\delta$ measurements?
  • Influence of the RF conditioning on $\delta$?

• Is there any influence of
  • the position of the pickups on the experimental results (what do they actually “see”)?
  • the geometry and bias voltage of the PU?
Thin Film NEG Coating for RF-Couplers
Ch.Benvenutti, CERN; D.Proch, DESY

NEG: Non Evaporable Getter pumps

Basic advantage:

- NEG coating can be placed inside the vacuum chamber, pumping at the spot
- low secondary electron yield
- in situ activation at moderate temperatures

Open questions:
RF loss?, dust free quality?, how many activation cycles needed/possible?
Idea: Use NEG coating for RF couplers

- will suppress multipacting by low secondary yield
- provides pumping at the RF surface, thus might eliminate RF discharge
  might reduce conditioning time

Best NEG candidate: Ti-HF-Zr compound
activation starts at 200°C
can easily be sputtered on RF surfaces
only 1.5 um thick film needed
Figure 5. Effective desorption yield of H₂, CO, CO₂, and CH₄ for an equiatomic TiZr coating. The measuring conditions are the same as indicated for Fig. 2. "Effective" here indicates the net desorption per impinging electron, as resulting from the competing action of surface degassing and pumping. Since CH₄ is not pumped, the measurements represent a real desorption yield for this gas.

Figure 6. Pumping speed variation as a function of the heating temperature for H₂ and CO of a TiZr coated sample. The measurements are carried out at 20°C after 2 h heating at the indicated temperature.
closed. During all measurements the system is pumped by a turbomolecular pump providing an effective pumping speed of about $751 \text{s}^{-1}$ for H$_2$.

For ultimate pressure measurements, two chambers 1 m long, 16 cm diameter, providing a total coated surface area of about 1 m$^2$, are linked together and connected to a pumping system via an orifice of $251 \text{s}^{-1}$ conductance for H$_2$. The pumping system, equipped with turbomolecular, sputter-ion and titanium sublimation (nitrogen cooled) pumps, is capable of an ultimate pressure lower than $10^{-12}$ Torr. At the free extremity of the coated chambers the pressure is monitored by means of an improved Heman type gauge, able to measure pressures down to the $10^{-14}$ Torr range.

Results

Pumping speed and ESD measurements have been carried out on chambers coated with Ti, Zr, Hf and some of their alloys. The results obtained on elemental coatings are shown in Fig. 2 together with those relative to a stainless steel vacuum chamber vacuum fired at 950°C.

Titanium follows closely the stainless steel reference curve up to 300°C, and then quickly drops by two orders of magnitude at 400°C. Hafnium and zirconium are slightly worse at the beginning, but activation starts at lower temperatures (about 200°C) and sets in more progressively, to reach the same value as titanium at 400°C. The results of Fig 2 are a clear indication that these elements are adequate for use on stainless steel chambers made of copper or aluminium alloys.

The results obtained on equiatomic binary Ti, Zr, Hf alloys (produced by means of composite cathodes made by intertwining two wires of different materials) are shown in Fig. 3. The alloys display a lower activation temperature compared to elemental coatings, and the lowest activation temperature corresponds to TiZr. In this case activation starts below 150°C and is practically completed at 300°C. Two hours at 250°C are sufficient for an almost complete activation.

Since Ti and Zr mixing provides the lowest activation temperature, the composition of the TiZr alloy has been varied by using cathodes obtained by intertwining two wires of one element and one of the other. The results, shown in Fig. 4, indicating that the equiatomic TiZr alloy still provides the lowest activation temperature, and that consequently it is the most adequate for applications where the heating temperature must be reduced to a minimum. This conclusion agrees with results, reported in literature, obtained by measuring the weight increase while heating samples of different Ti and Zr content in air at 700°C. In this case, the weight increase presents a maximum corresponding to equal atomic concentrations of these two elements, showing that this composition provides the highest oxygen diffusion coefficient.

The "effective" desorption yields (desorbed molecules par incident electron) for H$_2$, CO, CO$_2$ and the real CH$_4$ desorption yield for the equiatomic TiZr alloy are shown in Fig. 5. Note the very fast decrease of CO$_2$ and the leading presence of H$_2$ at all temperatures. All the other samples with different composition also display a similar behaviour.

The variation of pumping speed as a function of the heating
Figure 4
Experimental program

- measure multipacting with RF test resonator (reentrant Cu-cavity, 500MHz, at 300°K)
- NEG coating of Cu-electrodes
- measure multipacting after various conditions of NEG film

- Prepare NEG coating at inner surface of outer coax-conductor of TTF input coupler
- test conditioning and operational behavior at coupler test stand
This electron current might result in the stored energy in microwave breakdown. To suppress these resonant conditions can be avoided by proper resonant conditions for a parallel plate electric fields can be easily predicted and thus the right gap distance. In the case of DCs, however, multipacting is simulated by its. In the case of complicated three components a simulation of electrons very demanding. Furthermore the RF flow to change the geometry by the needed

electrodes

Figure 1: Test resonator
The lower horizontal axis is in (GHz x mm$^4$ x Ohm$^2$), detuning. By computing this with the band marked with $\pi$, note that there is only one picture; the higher order more prominent two-point of the band indicates where with typical design parameters, large kinetic energy for electrons in the picture correspond to.

The behavior of the multipacting standing wave to the traveling wave. We repeated the with no reflected wave, and shifted according to the simple SW.

Each multipacting level appears as a peak in the voltage of the peak voltage of the trajectories show, however that since the multipacting electron trajectories show.

Figure 2. Multipacting counter function for the test cavity curve in Figure 3 in [2]. Let us mention that the computed kinetic energy for the second order process is typically too low to appear with secondary electron yields characteristic e.g. to Niobium surfaces.

References

![Figure 3: Multipacting current vs. electric field gradient for Titanium on Copper](image)

[1]
Rel. Multipacting-Current vs. E-Field [kV/m]
The generator is locked to the cavity resonance and the antennas are calibrated at low RF field level. Then the RF power is modulated up to 20 watts with a saw-tooth generator of 0.1 Hz. The onset of multipacting current is measured and the order of multipacting is determined from the calibrated gap electric field gradient. The magnitude and the processing behavior of the multipacting current are measured the following way:

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>N</th>
<th>I [mA]</th>
<th>E1 [kV/m]</th>
<th>E2 [kV/m]</th>
<th>n</th>
<th>t [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>18</td>
<td>2.92</td>
<td>132.1</td>
<td>188.4</td>
<td>1</td>
<td>2080</td>
</tr>
<tr>
<td>Copper (heated at 400°C)</td>
<td>2</td>
<td>3.52</td>
<td>145.8</td>
<td>231.4</td>
<td>1</td>
<td>1223</td>
</tr>
<tr>
<td>Cu, stored one week in PE bag</td>
<td>2</td>
<td>3.30</td>
<td>82.5; 139.0</td>
<td>108.9; 192.8</td>
<td>2 ; 1</td>
<td>&gt;6500</td>
</tr>
<tr>
<td>Titanium on Copper</td>
<td>5</td>
<td>3.03</td>
<td>139.9</td>
<td>184.5</td>
<td>1</td>
<td>933.1</td>
</tr>
<tr>
<td>TiN on Copper</td>
<td>1</td>
<td>3.00</td>
<td>129.3</td>
<td>170.7</td>
<td>1</td>
<td>552</td>
</tr>
<tr>
<td>Titanium on Aluminum</td>
<td>2</td>
<td>2.88</td>
<td>141.8</td>
<td>183.4</td>
<td>1</td>
<td>885.5</td>
</tr>
<tr>
<td>Cu Ti, stored one week in PE bag</td>
<td>2</td>
<td>3.21</td>
<td>51.1; 123.6</td>
<td>68.1; 190.0</td>
<td>3 ; 1</td>
<td>&gt;6500</td>
</tr>
<tr>
<td>Aluminium</td>
<td>7</td>
<td>4.30</td>
<td>54.7</td>
<td>69.4</td>
<td>3</td>
<td>&gt;6500</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>18</td>
<td>3.37</td>
<td>69.3; 128.8</td>
<td>87.7; 147.6</td>
<td>2 ; 1</td>
<td>2781</td>
</tr>
<tr>
<td>Copper electrochemically plated on S.S.</td>
<td>7</td>
<td>3.33</td>
<td>132.7</td>
<td>183.8</td>
<td>1</td>
<td>2571</td>
</tr>
</tbody>
</table>

Table 2: Results of the multipacting measurements (N: number of measurements; I: multipacting current; E1, E2: electric gradient at onset, stop of multipacting current; n: order of multipacting; t: processing time)
Test of NEG - Coating

TEST 1: as received
TEST 2: after 24 h at 100°C
TEST 3: after 09 h at 200°C
TEST 4: after 24 h 200°C
TEST 5: flooded with dry N₂, Probes put out and in
TEST 6: after 24 h at 200°C
TEST 7: after 5 days of pumping, not heated
TEST 8: flooded with dry N₂ up to 1 mbar for 1 h
TEST 9: after 24 h at 250°C
TEST 10: after 24 h at 100°C. MP-Test starts at 50°C during cooldown
TEST 11: after 20 h at 250°C
TEST 14: Cu-Probe as Reference
Multipacting-Investigations of NEG-coated CERN-Samples

Time of Multipacting $t$ [s]

- CERN #1
- CERN #2
- CERN #1n
- CERN #2n
- CERN #3

Samples

- as received
- 100°C bakeout
- 200°C bakeout
- 250°C bakeout
- vented with N2
- 200°C bakeout
- 250°C bakeout
- 400°C bakeout
RF Losses in Cu Surface with TiZrV Coating

D.Proch, A.Zavadtsev
DESY

Copper surface of the fundamental mode input coupler may be coated by some material (for example TiZrV) to decrease secondary yield and thereby to decrease multipacting.

- Operating frequency \( f = 1.3 \text{ GHz} \)
- Conductivity of TiZrV \( \sigma_1 = 0.0286 \times 10^7 \text{ (Ohm*m)}^{-1} \)
- Conductivity of Cu \( \sigma_2 = 5.8 \times 10^7 \text{ (Ohm*m)}^{-1} \)
- Coating thickness \( t = 1 \mu\text{m} \)
The current density in the wall is

\[ j_x = A \sinh \tau_1 x + B \cosh \tau_1 x \]

\[ \tau_1 = \frac{1 + i}{\delta_1} \]

Penetration depth in the coating material is

\[ \delta_1 = \frac{1}{\sqrt{\pi f \mu_1 \sigma_1}} \]

\[ B = -\frac{\frac{\tau_2 \sigma_1}{\tau_1 \sigma_2} \cosh \tau_1 t}{\cosh \tau_1 t + \frac{\tau_2 \sigma_1}{\tau_1 \sigma_2} \sinh \tau_1 t} \]

Surface impedance is

\[ Z = -\frac{E_z}{H_y\bigg|_{x=0}} = (1+i)R_{Co} \cdot \frac{\sinh \tau_1 t + \frac{R_{Cu}}{R_{Co}} \cosh \tau_1 t}{\cosh \tau_1 t + \frac{R_{Cu}}{R_{Co}} \sinh \tau_1 t} \]

\( R_{Co} \) and \( R_{Cu} \) are the surface resistance of the coating material (TiZrV) and Cu.
The real and imaginary parts of the surface impedance depending on the coating thickness at 1.3 GHz and $\sigma_{\text{coal}} = 0.0268 \times 10^7 \text{ (Ohm} \times \text{m})^{-1}$.
Surface resistance depending on coating conductivity at 1.3 GHz and coating thickness 1, 2, 3, 5 and 10μm.
1. The test cavity is destined for the measurement of the surface resistance in the Cu-surface coated by TiZrV.

2. The existing Cu-samples coated by TiZrV should be used. These samples used for multipactoring investigation in DESY earlier.

3. TE\textsubscript{011}-mode is preferential because it has highest Q-factor and there is φ-component of the surface current only, i.e. there is no contact problem in the cavity.

4. Operating frequency 9 GHz was chosen because:
   - the surface resistance of the coated surface increases with the increasing of the frequency, and therefore the measurement accuracy increases also;
   - sample size corresponds to the size of the TE\textsubscript{011}-cavity approximately at 9 GHz.
Q-factor of test cavity vs. coating thickness for coating conductivity $0.0268 \times 10^7$ (Ohm*m)$^{-1}$
Q-factor of test cavity vs. coating conductivity for 1.2, 3, 5 and 10 μm coating thickness.
Test cavity parameters and resistance measurement

<table>
<thead>
<tr>
<th>Cavity material</th>
<th>Cu</th>
<th>Cu + TiZrV coating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency, GHz</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Coat. thickness, μm</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Coat. conductivity, (Ohm*m)^{-1}</td>
<td>2.86*10^5</td>
<td></td>
</tr>
<tr>
<td>Relative surface resistance of the sample R_{sample}/R_{Cu}</td>
<td>1</td>
<td>1.039</td>
</tr>
<tr>
<td>Q</td>
<td>28610</td>
<td>28350</td>
</tr>
<tr>
<td>k</td>
<td>0.237</td>
<td></td>
</tr>
</tbody>
</table>

Measured parameters

<table>
<thead>
<tr>
<th>Coating parameters:</th>
<th>Cu + TiZrV coating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating conductivity, (Ohm*m)</td>
<td>2.86*10^5</td>
</tr>
<tr>
<td>Coating thickness, μm</td>
<td>1.61</td>
</tr>
<tr>
<td>Relative surface resistance of the sample at 1.3 GHz R_{sample}/R_{Cu}</td>
<td>1.015</td>
</tr>
</tbody>
</table>

Analyzed parameters

\[
\frac{R_{sample}}{R_{Cu}} = 1 + \frac{1}{k} \left( \frac{Q_{Cu}}{Q_{sample}} - 1 \right)
\]

k is the power loss in the Cu sample divided by the whole power loss in the cavity without coating.
Conclusion.

1. RF power loss increasing because the coating is 0.4% for 1μm coating thickness and 0.0286*10^7 (Ohm*m)^{-1} coating conductivity.

2. RF power loss increasing because the coating is 2.5% for 1μm coating thickness and 0.2*10^7 (Ohm*m)^{-1} coating conductivity.

3. RF power loss increasing because the coating is 2 times for 10μm coating thickness and 0.0286*10^7 (Ohm*m)^{-1} coating conductivity.

4. RF power loss increasing because the coating is 4.8 times for 10μm coating thickness and 0.2*10^7 (Ohm*m)^{-1} coating conductivity.

5. The result of the measurement of test cavity is surface resistance at 9 GHz. There are two indefinite parameters for the coating: thickness and conductivity. We can assume that one of them is equal to designed value and fine the second one. The difference of the surface resistance of described coating at 1.3 GHz for these two cases is 0.1%.

6. The test cavity measurement is sufficiently sensitive to the loss value. 1.3% RF loss increasing because the coating was successfully measured on the Cu sample coated by TiZrV.
Current activities in TiN coating at DESY

J. Lorkiewicz, B. Dwersteg
DESY

Technique used: Ti evaporation in NH₃ atmosphere.

- Selection of coating procedure.
- Coating of flat WG windows for main TTF coupler.
- Coating of cylindrical windows for DESY – TTF- III coupler.
Alu-sample #14, Ti coating test No. 23. Date of coating 04.11.99
Heating current 17 A, deposition time 48 s. Chamber heating off

Multipactingstrom-Verlauf

Feldstärkeverlauf
Coating of electrodes for RF test resonator

Coating parameters:

- deposition rate: 9nm/min, 20 nm/min,
- final layer thickness: 4 - 40 nm,
- \( \text{NH}_3 \) pressure during deposition: \( 10^{-3} \) mbar,
- substrate temperature: \( 25^\circ\text{C}, 150^\circ\text{C} \),
- postprocessing: \( \text{NH}_3 \) pressure 150 - 750 mbar, duration time 20 hours - 1 week.
# Test results from DESY coaxial resonator

<table>
<thead>
<tr>
<th>Sample</th>
<th>Substrat temperature</th>
<th>Deposition rate (atmosphere)</th>
<th>Layer thickness</th>
<th>Further processing</th>
<th>Layer resistivity at 3000 K</th>
<th>Layer resistivity at 70 K (Mohm/sq.)</th>
<th>Multipactoring time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Al</td>
<td>before processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Cu</td>
<td>before processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Cu</td>
<td>25°C</td>
<td>20 nm/min (res. gas)</td>
<td>ca. 40 nm</td>
<td>no</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Cu</td>
<td>25°C</td>
<td>20 nm/min (NH₃)</td>
<td>ca. 40 nm</td>
<td>no</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Cu</td>
<td>150°C</td>
<td>9 nm/min (10⁻³ mbar NH₃)</td>
<td>13 nm</td>
<td>3 days</td>
<td>150 mbar NH₃</td>
<td>960</td>
<td>14600</td>
</tr>
<tr>
<td>6. Al</td>
<td>150°C</td>
<td>9 nm/min (10⁻³ mbar NH₃)</td>
<td>15 nm</td>
<td>2 days</td>
<td>300 mbar NH₃</td>
<td>55</td>
<td>960</td>
</tr>
<tr>
<td>7. Al</td>
<td>150°C</td>
<td>9 nm/min (10⁻³ mbar NH₃)</td>
<td>ca. 7 nm</td>
<td>3 days</td>
<td>250 mbar NH₃</td>
<td>2900</td>
<td>195000</td>
</tr>
<tr>
<td>8. Al</td>
<td>25°C</td>
<td>9 nm/min (10⁻³ mbar NH₃)</td>
<td>7 nm</td>
<td>20 hours</td>
<td>700 mbar NH₃</td>
<td>11700</td>
<td>195000</td>
</tr>
<tr>
<td>9. Al</td>
<td>25°C</td>
<td>9 nm/min (10⁻³ mbar NH₃)</td>
<td>7 nm</td>
<td>23 hours</td>
<td>700 mbar NH₃</td>
<td>24300</td>
<td>290000</td>
</tr>
<tr>
<td>10. Al</td>
<td>150°C</td>
<td>9 nm/min (10⁻³ mbar NH₃)</td>
<td>ca. 4 nm</td>
<td>24 hours</td>
<td>200 mbar NH₃</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Al</td>
<td>150°C</td>
<td>9 nm/min (10⁻³ mbar NH₃)</td>
<td>7 nm</td>
<td>21 hours</td>
<td>750 mbar NH₃</td>
<td>0.6</td>
<td>4.5</td>
</tr>
<tr>
<td>12. Al</td>
<td>150°C</td>
<td>9 nm/min (10⁻³ mbar NH₃)</td>
<td>7 - 8 nm</td>
<td>1 week</td>
<td>400 mbar NH₃</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FhG-IST:Willich:December 20,1999: SIMS Quantitative Depth
Profile: DESY/Dwersteg:#1
(Cu mit Beschichtung TiN)
--- Repetition - several H2

FINAL TTF-Main-Coupler

Pulse frequency 109 (reduced to 0.8) ms

Peak transmitted power \( \approx 1\mathrm{MW} \)

---
2 CF16 Flanges on both sides for e- and light detection

connection for either vacuum tight or standard rectangular WR 650 waveguide

32.55 wide x 165.1 high

stainless steel

circular Al2O3 ceramic disk of 218 mm diameter

circular pillbox in rectangular waveguide

DESY High Power WG-Window

connection for either vacuum tight or standard rectangular WR 650 waveguide

W.D. Möller, TTF coupler meeting, Saclay, October 19-20, 1998
Ti wire loop with supporting structure

\[
\text{deposition rate} = 8.5 \ \frac{\text{nm}}{\text{min}}
\]

\[
\text{deposition rate} = 3.5 \ \frac{\text{nm}}{\text{min}}
\]

\[
\text{deposition rate} = 10 \ \frac{\text{nm}}{\text{min}}
\]

\[
\text{deposition rate} = 15 \ \frac{\text{nm}}{\text{min}}
\]
Cross-sectional view of waveguide windows coating device

- 3x venting with $N_2$
- to the pump
- basic pressure $< 10^{-5}$ mbar

- Ti wire heated up slowly
- 2x venting with $N$
- coating at 1480°C
- wire temp. $10^{-3}$ mbar
- $NH_3$

supporting structure

Ti wire

window

ceramic disc
"G"-series waveguide windows coating - processing parameters

<table>
<thead>
<tr>
<th>of WG window coated</th>
<th>Maximum deposition rate on the disc</th>
<th>Ammonia pressure during coating</th>
<th>Estimated layer thickness range</th>
<th>Postprocessing NH₃ pressure, duration time</th>
<th>Layer resistance after coating after postprocessing</th>
<th>Colour the disc surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>G-16</td>
<td>12 nm/min</td>
<td>2E-3 mbar</td>
<td>5 - 22 nm</td>
<td>940 mbar (41 hours)</td>
<td>3.3 Kohm/sq.</td>
<td>metallic grey, pale in the centre</td>
</tr>
<tr>
<td>G-17</td>
<td>12 nm/min</td>
<td>2E-3 mbar</td>
<td>5 - 22 nm</td>
<td>970 mbar (11 hours)</td>
<td>7.3 Kohm/sq.</td>
<td>metallic grey, pale in the centre</td>
</tr>
<tr>
<td>G-18</td>
<td>12 nm/min</td>
<td>2E-3 mbar</td>
<td>3 - 12 nm</td>
<td>860 mbar (40 hours)</td>
<td>161 Kohm/sq.</td>
<td>metallic grey, grey-yellowish, pale</td>
</tr>
<tr>
<td>G-20</td>
<td>12 nm/min</td>
<td>2E-3 mbar</td>
<td>3 - 12 nm</td>
<td>850 mbar (18 hours)</td>
<td>54 Kohm/sq.</td>
<td>metallic grey, grey-yellowish, pale</td>
</tr>
<tr>
<td>G-21</td>
<td>12 nm/min</td>
<td>2E-3 mbar</td>
<td>3 - 12 nm</td>
<td>700 mbar (17 hours)</td>
<td>28 Kohm/sq.</td>
<td>metallic grey, grey-yellowish, pale</td>
</tr>
<tr>
<td>G-22</td>
<td>12 nm/min</td>
<td>2E-3 mbar</td>
<td>3 - 12 nm</td>
<td>650 mbar (38 hours)</td>
<td>223 Kohm/sq.</td>
<td>metallic grey, grey-yellowish, pale</td>
</tr>
<tr>
<td>G-23</td>
<td>12 nm/min</td>
<td>2E-3 mbar</td>
<td>3 - 12 nm</td>
<td>ca.900 mbar (60 hours)</td>
<td>949 Kohm/sq.</td>
<td>metallic grey, grey-yellowish, pale</td>
</tr>
<tr>
<td>G-24</td>
<td>5 nm/min</td>
<td>2E-3 mbar</td>
<td>3 - 12 nm</td>
<td>780 mbar (88 hours)</td>
<td>1277 Kohm/sq.</td>
<td>grey-yellowish, pale</td>
</tr>
<tr>
<td>G-25</td>
<td>5 nm/min</td>
<td>2E-3 mbar</td>
<td>3 - 12 nm</td>
<td>ca.700 mbar (63 hours)</td>
<td>330 Kohm/sq.</td>
<td>grey-yellowish, pale</td>
</tr>
<tr>
<td>G-26</td>
<td>5 nm/min</td>
<td>2E-3 mbar</td>
<td>3 - 12 nm</td>
<td>ca.620 mbar (2 weeks)</td>
<td>150 Kohm/sq.</td>
<td>grey-yellowish, pale</td>
</tr>
</tbody>
</table>

---

**RF window G-17, Ti-layer resistance/sq vs time**

- Coating: 9.6, 12 nm/min
- Postprocessing in ammonia: 970 mbar, 11 hours
- Exposure to the air: 12 hours

**G-23 window coating, Ti-layer resistance/sq vs time**

- Coating: 6.6, 12 nm/min
- Postprocessing in ammonia: 960 mbar, 50 hours
- Exposure to the air: 27 hours
Layer resistivity distribution on the disc

G-17
35 hours in the air

G - 25
6 hours in the air
TiN coating of cylindrical windows for DESY-TTF-III coupler

70 K windows - 20 pcs

"warm" windows - 20 pcs

Step 2 - coating of cylindrical surfaces

copper collar

Step 1 - end plates coating

Ti wire

Ti wire loop
Summary

Experience with Ti deposition from vapour phase:

- ADVANTAGES:
  - Can be used for surfaces with difficult access,
  - The layer thickness distribution is calculable and well predictable,
  - The process is relatively slow and easy to control,
  - There is no need of substrate movement (rotation) under vacuum to reach good layer homogeneity.

DRAWBACKS:

- Slow Ti-TiN conversion,
- Possible problems with high residual conductivity,
- Using a chemically active atmosphere (NH₃) in a vacuum system (corrosion, no possibility of using cold traps).
Plans for the future

A new multipurpose device for antimultipactor surface processing:

- large number of RF components coated simultaneously,

- possible adaptation for other techniques (e.g. sputtering),

- monitoring and control system.