New ASDEX Upgrade ICRF antenna vacuum feedthrough: design review

O. Girka[1], W. Helou[2], H. Fünfgelder[1], H. Faugel[1],
F. Paulus[1], R. Ochoukov[1], W. Tierens[1,3], V. Bobkov[1]
[1]Max-Planck-Institut für Plasmaphysik, Boltzmannstraße 2, D-85748 Garching, Germany
[2] ITER Organization, Route de Vinon-sur-Verdon, CS 90 046, 13067 St. Paul Lez Durance Cedex, France
[3]Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831, USA

Introduction

ICRF heating is considered as a candidate for the future EU-DEMO reactor, primarily as a tool to enter the high confinement regimes. ICRF vacuum feedthrough is a critical component which can severely limit the ICRF power availability and requires careful design [1]. Feedthrough design elements can be tested on the present experiments, such as ASDEX Upgrade (AUG). The current AUG ICRF antenna vacuum feedthrough has been in operation since 1992, and thoroughly demonstrated its robustness and reliability during 30 years of operation. Nonetheless, its 6-inch ceramic front window imposes limits on the voltage stand-off and thus on ICRF power [2]. This work shows the results on dielectric spectroscopy for the samples of commercially available ceramics: A479S, A479U, A601L and CO720 which are currently available as candidate materials for the feedthrough. Measurements of dielectric properties are used as an input to Ansys HFSS model for the front and rear ceramic windows. RF windows volume power losses and reflection coefficients are calculated for two of four ceramic types – A479S and CO720, and compared for the whole operating frequency range.

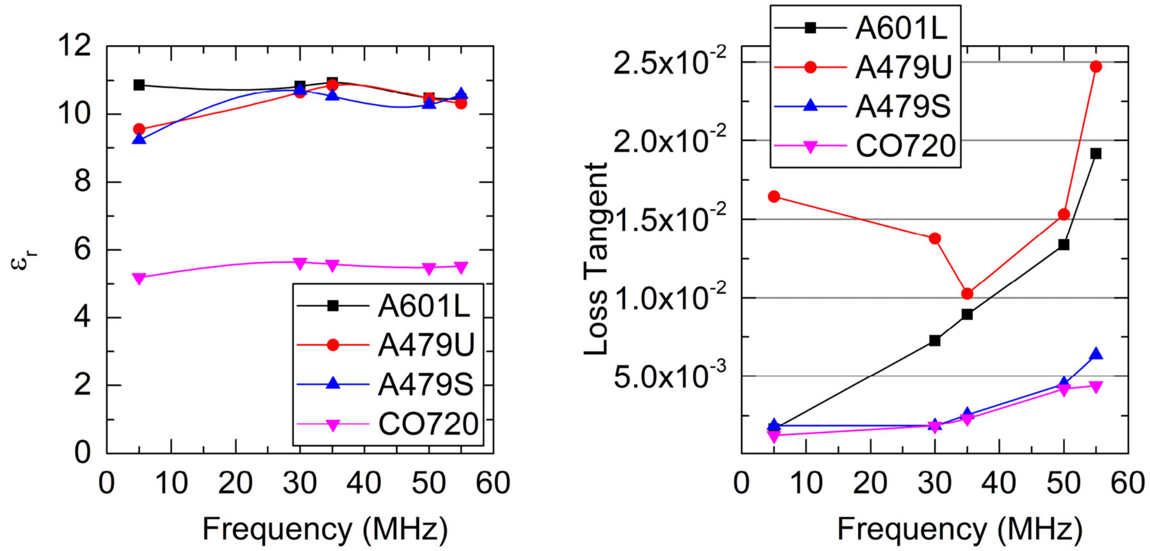
Materials and methods

New AUG ICRF antenna vacuum feedthrough design concept was described previously [2]. RF windows are positioned comparatively far from the antenna in order to minimize neutron flux and fluence in new design. An absorption of the transmitted power is the next critical parameter after the stability under the neutron irradiation. RF windows drawings of the current feedthrough design back to 1990 indicate Al300 as dielectric material. HFSS calculations for new design in [2] were carried out based on the datasheet for Al300 (Mac-A976W) alumina: the relative permittivity of 9.9 and the presumed dielectric loss tangent of $2x10^{-4}$ [3]. A small change in fraction of absorption of the transmitted power can lead to temperature-gradient-induced mechanical stress and, correspondently, risk of RF window damage. Datasheets of commercially available ceramics barely reflect the values for loss tangent in frequency range from 1 to 100 MHz. In the past, dielectric spectroscopy of alumina ceramics over a wide frequency range was carried out by CIEMAT team [4]. In [4] measured loss tangent variation was three orders of magnitude depending on impurities concentration and type. Due to a wide measurement range, measured data provide two-three values from 1 to 100 MHz. Other than alumina ceramics were under consideration for mm-wave windows [5], where leading position was taken by microwave plasma assisted chemical vapor deposition diamond due to low millimeter-wave losses: tan $\delta = 1\text{-}3\times10^{-5}$ [6]. Cordierite-based ceramics are widely used as an electromagnetically transparent, structurally robust and environmentally resistant enclosure (the so-called "radome") of radar antenna for ground-based systems to modern avionics in military aircraft and missiles [7]. Low dielectric constant (ε_r) that controls the reflected fraction of electromagnetic signals and comparatively low dielectric loss tangent (tan δ) that controls absorption of electromagnetic waves through the radome walls are two critical material properties that determine the radome functionality [8]. Cordierite dielectric, structural and thermomechanical properties were measured at Terahertz range [8].

For the new AUG ICRF antenna vacuum feedthrough design four ceramic types are considered: A479S, A479U, A601L and CO720 from Kyocera. Dielectric spectroscopy measurements are carried out with HP 4342A Q Meter [9] for ceramic samples 38 mm in diameter and 5 mm thick. The results for ε_r and tan δ are shown in Fig. 1. One can see in Fig. 1, that RF losses are comparatively high for A601L and A479U and remarkably lower for A479S and CO720. The significant difference in ε_r for alumina and cordierite motivated to launch transmission line HFSS simulation, keeping inner and outer conductor as well as ceramic dimensions same as in [2] for the front and rear windows and varying dielectric properties. The results from Ansys HFSS model are shown in Fig. 2. One can conclude form Fig. 2, that lower ε_r ceramic window with same dimensions provide slightly higher values of reflection coefficient. Meantime, lower ε_r ceramic shows close to the factor of 2 lower power losses per window. Taking this into account, A479S and CO720 are the most suitable materials for the RF windows from the materials tested. However, these are characterized by higher losses compared to datasheet values for the ceramics used in AUG RF windows previously.

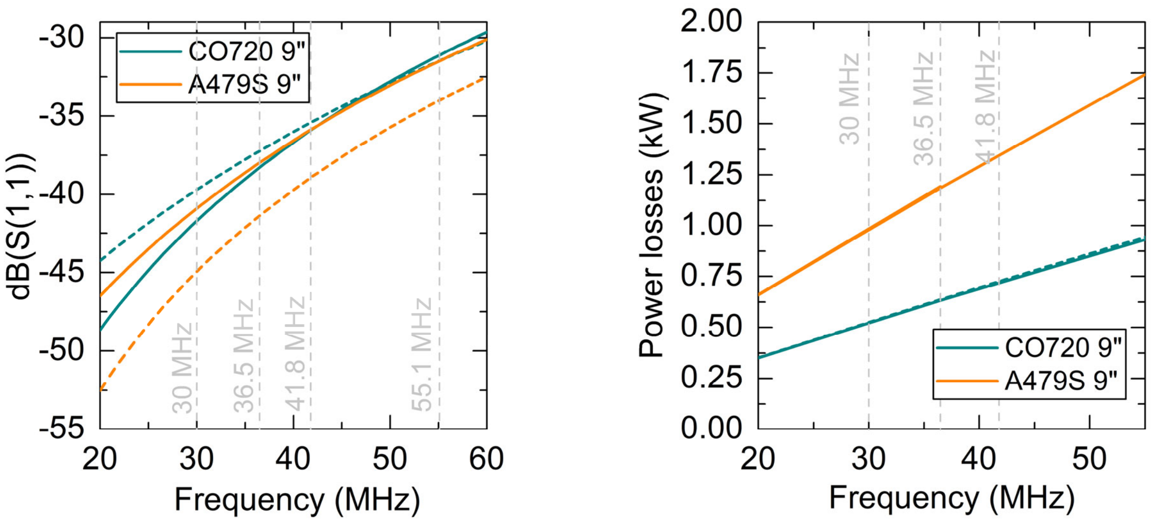
Discussion and conclusions

Modelling of the new feedthrough design with two 9-inch ceramic windows reported in [2] shows less than 1.9 kV/mm in the torus and the private vacuum, what can serve as a predesign for DEMO. The standing wave patterns indicate that the new RF windows' position is closer to the voltage node. Two of four considered commercially available ceramics are currently the most suitable for AUG RF windows manufacturing: A479S and CO720. Cordierite-based ceramic window with lower ε_r shows slightly higher reflection coefficient S11, but close to the factor of two lower power losses per window compared to alumina-based ceramic with similar loss tangent, although the latter is significantly higher than the presumed



a b

Fig. 1. Measured dielectric constant as a function of frequency if shown in (a). Measured loss tangent as a function of frequency is shown in (b).



a b

Fig. 2. Calculated reflection coefficient S11 as a function of frequency (a): orange solid and dashed line show S11 for front and rear window made of A479S; royal green solid and dashed line show S11 for front and rear window made of CO720. Calculated volume power losses as a function of frequency for 1 MW of incident power (b) for A479S (orange) and CO720 (royal green) 9-inch windows.

value for the AUG RF ceramics used until now. Reflection coefficient is in the well acceptable range from -30 to -55 dB for the whole operating frequency range for both ceramic types. AUG feedthrough design is not based on ceramic to metal brazing, so main criteria are the lowest possible power losses, lowest power reflection, highest thermomechanical stability. Once decided on the choice of ceramics, the optimized feedthrough design is planned to be tested in a full-wavelength resonator testbed facility using one of the AUG RF generators, in order to get experimental E-fields distribution and return loss coefficients.

Acknowledgements

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them. The views and opinions expressed herein do not necessarily reflect those of the ITER Organization. The authors want to acknowledge and specially thank Mr. Gerhard Siegl for his generous support and fruitful discussions.

References

[1] H. Wedler, F. Wesner, W. Becker, R. Fritsch. Fusion Eng. Design. 24 (1994) 75-81 https://doi.org/10.1016/0920-3796(94)90038-8

[2] O. Girka, W. Helou, H. Faugel, W. Tierens, V. Bobkov. Fusion Eng. Design 193 (2023) 113646 https://doi.org/10.1016/j.fusengdes.2023.113646

[3] https://www.morganthermalceramics.com/media/4810/al300.pdf

[4] R. Vila, M Gonzalez, J. Molla, A. Ibarra. Journal of Nuclear Materials 253 (1998) 141–148 https://doi.org/10.1016/S0022-3115(97)00308-5

[5] M. Thumm. Proc. Radio Frequency Workshop, AIP Conf. Proc. 474 (1998) pp. 146–162 https://doi.org/10.1063/1.59039

[6] M.K. Thumm; W. Kasparek. IEEE transactions on plasma science, 30 (2002) 3 https://doi.org/10.1109/TPS.2002.801653

[7] A. Nag, R. Ramachandra Rao, P.K. Panda. Ceramics International, 47 (2021) 20793-20806 https://doi.org/10.1016/j.ceramint.2021.04.203

[8] A.V. Zaichuk, A.A. Amelina, Y.S. Hordieiev, Y.R. Kalishenko. Open Ceramics 15 (2023) 100377 https://doi.org/10.1016/j.oceram.2023.100377

[9] HP Q meter 4342 A operating and service manual. Agilent Technologies, Inc, (1983)