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ITER ECRH Upper Launcher: Test plan for qualification of the Diamond Torus Window Prototype III

Sabine Schreck[a,*], Gaetano Aiello[a], Andreas Meier[a], Dirk Strauss[a], Mario Gagliardi[b], Gabriella Saibene[b], Theo Scherer[a]

[a] Karlsruhe Institute of Technology, Institute for Applied Materials, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany
[b] F4E, Antennas and Plasma Engineering, Josep Pla 2, Torres Diagonal Litoral B3, 08019 Barcelona, Spain

HIGHLIGHTS

- A qualification program for the ITER diamond torus window is being developed.
- The testing program for the qualification of the bare diamond disk is defined.
- First qualification tests show a very good quality of the diamond disk prototypes.

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ABSTRACT

The diamond window is part of the electron cyclotron heating upper launcher system for ITER. Together with the isolation valve it constitutes the primary vacuum boundary and it also acts as first tritium barrier. Therefore the window is classified as Safety/Protection Important Component (SIC/PIC) with the nuclear safety function "confinement". As the diamond window unit is not entirely covered by standard codes, an ad-hoc qualification program needs to be defined, including analysis, prototyping and testing. In the framework of a contract with F4E, the test program for a diamond window prototype is being developed with the aim to prove its operability for normal, accidental and incidental conditions as identified in the ITER load specifications. Tests range from dielectric loss measurements for the bare Chemical Vapour Deposition (CVD) diamond disk up to mechanical and vacuum tests for the complete window assembly. Finally mm-wave properties have to be characterized for the complete window. A clear definition of the testing requirements and of the acceptance criteria is necessary as well as a complete documentation of the process.

This paper will present the development of the test plan for a window prototype, which is currently under manufacturing. First tests are directed to the characterization of the bare diamond disk with a focus on its dielectric properties.

1. Introduction

The ITER ECRH system consists of one equatorial EC launcher (EL) and four upper launchers (UL). The upper launchers are connected via transmission lines to the ITER gyrotrons providing up to 20 MW mm-wave power at 170 GHz and the main purpose is to drive local current with the aim to control the plasma instabilities (mitigate NTMs (Neoclassical Tearing Mode)) [1]. The diamond window is located in the port cell environment between the launcher and the transmission line (Fig. 1). The diamond window unit consists of a synthetic polycrystalline diamond disk produced by 'Microwave Plasma Assisted (MPA)' chemical vapour deposition (CVD) mounted in a system of metallic parts (copper/steel). The requirements to such a CVD diamond window are an ultra-low loss tangent of the disk ($\tan\delta < 2 \times 10^{-5}$) and a robust structural design against the expected loads allowing the transmission of up to 1.5 MW into the plasma via the launcher.

The window unit is part of the first ITER confinement system and thus it has the most stringent requirements in the ITER safety (SIC1/PIC1), quality, vacuum, seismic and tritium classifications.

As the design, the manufacturing and the qualification of the diamond window cannot be completely covered by standard codes, a specific qualification program has to be developed. Within this program, acceptance criteria for clearly defined tests have to be

* Corresponding author.
E-mail address: sabine.schreck@kit.edu (S. Schreck).

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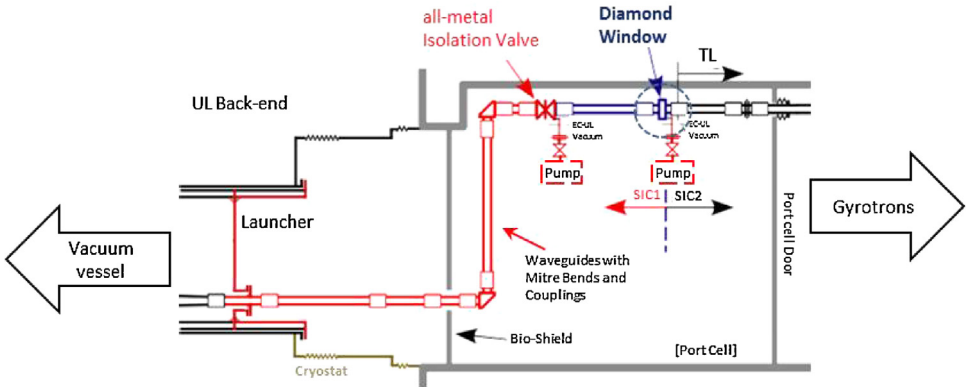

Fig. 1. A schematic (from EC Safety System Philosophy – ITER_D_BN7UPS) illustrating the principle waveguide components in the port cell region. The diamond window is a SIC-1 component located directly at the barrier to SIC 2.

determined in order to guarantee the overall functionality of the component. The testing and qualification plan needs to respect and fulfill the requirements of nuclear safety, as postulated in the ITER Preliminary Safety Report (RPrS). All testing conditions have to be compliant with the design driver loading conditions expected during the lifetime of an ITER window. A definition of damage limits is necessary and the test results have to be compared against these limits. The complete procedure needs to be accompanied by supporting analysis.

In the framework of a contract with F4E, KIT develops the testing and qualification program for a window prototype and will execute the prototype tests. The tests range from standard tests for geometry control, vacuum and leakage tests up to mm-wave-transmission tests for which a dedicated measurement facility (FABRY-PEROT-resonator) is available at KIT.

The prototype to be tested (also called Prototype III) is built based on the design proposed by KIT, which is expected to represent the final design of the ITER ECRH UL window. Two disks procured by F4E to be used for the window prototype were already manufactured by the company Diamond Materials (Freiburg, Germany) and first results on their dielectric properties are available.

2. Updated window design for Prototype III

With respect to the previous window prototypes (Prototype I and Prototype II) [2], the design of the window was updated and optimized by FEM analyses and the application of the ASME Sec. III – Subsection NC code. This is the selected code for the design, manufacturing, assembling (i.e. the joining) and qualification of the diamond window unit, being classified as an ASME class 2 component. The design driver load combination for the unit was taken into account in the FEM analyses [3]. The updated window design is shown in Figs. 2 and 3. The window unit basically consists of a 1.11 mm thick (Ø 80 mm) diamond disk brazed to two oxygen-free copper cuffs and this structure is then integrated into a metallic housing by welding. Two nickel rings, named spacer rings, connect the cuffs to corrugated stainless steel waveguides, which are inserted into the cuffs leaving a 100 μm gap with the diamond disk. This 100 μm gap has been evaluated during Prototype II manufacturing and testing (within F4E-OPE-140) [2,4].

In general, the design strategy was to have a very rigid outer window frame able to withstand the external loads acting on the unit while thin copper cuffs brazed to the diamond allow indirect cooling of the disk (i.e., no direct contact between disk and coolant). Diagnostic pipes have been added to allow real-time monitoring

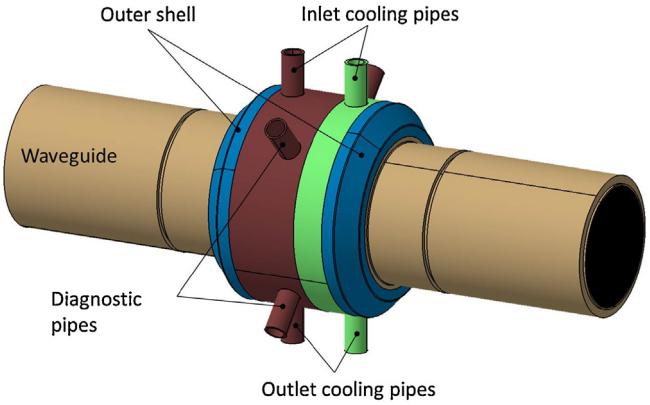

Fig. 2. Current design of the ITER window unit.

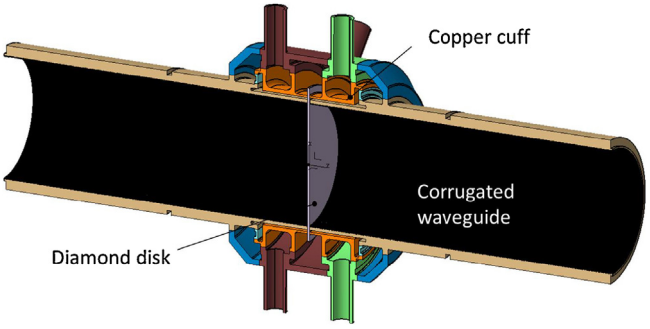

Fig. 3. Section view of the ITER window unit.

of the interspaces inside the unit. The brazing is carried out only between the disk and the cuffs while all other parts are joined by welding.

The requirements for the manufacturing, assembling and examination of the window unit prototype according to ASME and according to the mm-wave properties of the window are collected in a Technical Specification (TS) document. This also provides the specifications for the testing at manufacturer site of pre-manufacturing mock-ups and of the diamond window assembly itself. One general requirement is to produce an appropriate documentation for the manufacturing process including equipment descriptions, process parameters, environmental conditions, material certificates, etc.

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