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Testing of prototypical ITER electron cyclotron heating (ECH) transmission line components at representative ITER conditions has been carried out at the Japan Atomic Energy Agency (JAEA) rf test stand. Based on results to date, it appears that the ITER requirement for 2 MW cw operation of the transmission line with high transmission efficiency is achievable. The tests showed that improvement in the polarizer miter bend mirror performance is needed and that it is critical to have accurate alignment of the gyrotron output into the waveguide. Progress in both areas is being made. Additional testing of components at the JAEA RF test stand is planned.

Over the last several years, development of 170 GHz gyrotrons for ITER has yielded gyrotrons with both high power and long pulse length capability. In particular, the 170 GHz gyrotron at the JAEA rf test stand has generated 0.8 MW/1 h and 1 MW/800 s. This capability has enabled the possibility of testing prototypical ITER ECH transmission line components at representative ITER conditions. The US Department of Energy and JAEA have established a collaboration to test prototypical components at the JAEA rf test stand.

The first tests at representative ITER conditions of some GA components (waveguides and miter bends) were carried out at the JAEA rf test stand in 2006 [1]. Additional components were tested during August through December 2008 [2], and more tests are planned in 2010. The components tested in 2008 included polarizer miter bends, waveguides, very low diffraction loss miter bends and a dc break. Components to be tested in 2010 include a waveguide switch, waveguide water cooling bars, a sliding waveguide joint and polarizer miter bends with improved grooved mirrors.

For the testing in 2008, JAEA measurements and analyses showed that the beam entering the test section had a significant content of higher order modes due to misalignment of the Matching Optics Unit (MOU) output into the waveguide. As reported in Ref. 3, the $HE_{11}$ content at the end of the 7-m transmission line prior to the test components was only 66%. The $LP_{11}$ (equivalent to $HE_{21}$ + $TE_{01}/TM_{01}$) mode content was calculated to be 27%, with the remaining 7% power in other high order modes. Following the 2008 tests, JAEA improved the alignment technique for their two MOU mirrors and were able to achieve 93% $HE_{11}$ mode purity [3,4]. This improvement is approaching the ITER requirement of >95% $HE_{11}$ mode purity in the ITER transmission line.

In one test, two polarizer miter bends with a 2-m length of wave-guide between them were tested. On the downstream side of the polarizers, an additional 2-m section of waveguide and a dc break were tested. Similarly, two low diffraction loss miter bends (LDLMBs) were tested with a 1-m section of waveguide between them.

Numerous shots of approximately 600 kW for 240 s were injected into the transmission line for the 2008 tests. Calorimetric measurements of the heat dissipated in miter bend mirrors were made, and IR and RTD measurements were made of waveguide temperatures during the pulses. Results on the various components tested are described below.

Measurements of the dc break, which has water-cooled arms, showed that the temperature increase of the outer surface of the ceramic insulator was about 8°C which is equivalent to 27°C for 2 MW transmission – this increase is still less than a safe maximum temperature increase of about 50°C. Because of the presence of higher order modes, this increase was larger than would have been the case with pure $HE_{11}$ transmission. For pure $HE_{11}$, the calculated temperature increase is about 10°C for 2 MW cw transmission. The radiated rf power measured at 50 cm was found to be equivalent to 0.7 mW/cm$^2$ at 2 MW, well within the 5 mW/cm$^2$ safety standard.

The polarizer mirrors exhibited higher losses than predicted from theory. The losses in both the polarization rotator and circular polarizer showed the theoretically predicted variation with perpendicular H-field, but the magnitude of the losses varied from 1.7 to 2.9 times the theoretical losses at room temperature. This relatively high loss is attributed to a resistive recast layer on the surface of the copper grooves created during the wire-EDM machining process. The polarizers were returned to GA so that the mirror surfaces could be re-machined using conventional NC machining, and the mirrors will be retested at the JAEA rf test stand early in 2010. Figure 1 shows the appearance of the polarizer grooves before and after re-machining. Even with the resistive surface layer, finite element thermal and stress analyses show that the polarizers are suitable for up to 1 MW cw operation when mirror angles are optimized for lowest loss operation.

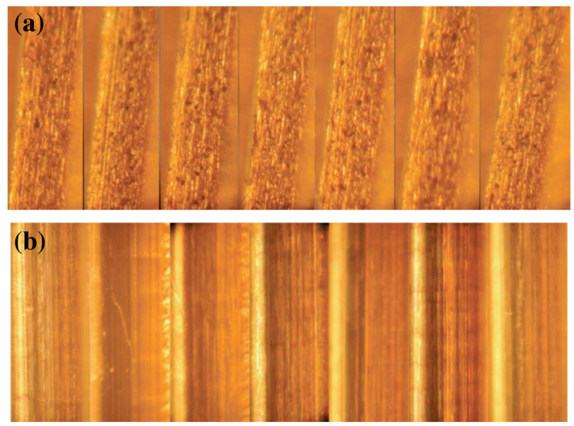

Fig. 1. (a) Polarizer grooves after wire EDM, (b) Polarizer grooves after recast layer removed by mechanical machining

The tests on the LDLMBs showed that mirror losses, especially on the downstream LDLMB (0.21%), were close to the theoretical prediction (0.16% at room temperature). However, losses in the adjacent waveguides were higher than expected for pure $HE_{11}$ transmission because of higher ohmic and mode conversion losses of the $LP_{11}$ and other high order modes. The temperature increase of the waveguide section downstream of the second LDLMB was about 10.5°C, vs. the 2.5°C increase expected for pure $HE_{11}$ transmission for the power and pulse length conditions of the experiment. For pure $HE_{11}$ entering the LDLMBs, no modes near cutoff should be generated. The higher observed heating is attributed to modes near cutoff generated by the LDLMBs for non-$HE_{11}$ input. The temperature increase of the LDLMB arms and adjacent waveguide sections was lower at the more downstream locations. This was consistent with the LDLMBs not generating higher order modes from the transmitted $HE_{11}$ mode. The temperature rise in waveguides next to the polarizer miter bends in these 2008 tests and next to standard miter bends in the 2006 tests [1] was about 40°C, which is much higher than the 10.5°C rise next to the downstream LDLMB in the 2008 tests. We can conclude that the structure of LDLMBs substantially reduces the conversion to modes with high attenuation.

The tests conducted at the JAEA rf test stand are valuable in validating designs and determining where design improvements are needed.

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