CHARACTERISTICS OF DIAMOND WINDOWS ON THE 1 MW, 110 GHz GYROTRON SYSTEMS ON THE DIII–D TOKAMAK

by

Y.A. GORELOV, J. LOHR, R.W. CALLIS, and D. PONCE

AUGUST 2002
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This is a preprint of a paper to be presented at the Twenty-Seventh International Conference on Infrared and Millimeter Waves, September 22–26, 2002, San Diego, California, and to be published in the Proceedings.

Work supported by the U.S. Department of Energy under Contract Nos. DE-AC03-99ER54463

GENERAL ATOMICS PROJECT 30033
AUGUST 2002
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Y.A. Gorelov, J. Lohr, P. Borchard, R.W. Callis, and D. Ponce

General Atomics, P.O. Box 85608, San Diego, California 92186-5608

Abstract. Diamond disks made using the chemical vapor deposition (CVD) technique are now in common use as gyrotron output windows. The low millimeter wave losses and excellent thermal conductivity of diamond have made it possible to use such windows in gyrotrons with ~1 MW output power and pulse length up to and greater than 10 s. A ubiquitous characteristic of diamond gyrotron windows is the presence of apparent hot spots in the infrared images registered during rf pulses. Many of these spots are co-located with bright points seen in visible video images. The spots do not seem to compromise the integrity of the windows. Analysis of the infrared observations on several different gyrotrons operating at the DIII-D tokamak are reported.

I. INTRODUCTION

The DIII-D electron cyclotron heating (ECH) system is comprised of five operational gyrotrons operating at a frequency of 110 GHz. The total rf power injected into the tokamak vessel exceeds 2.5 MW. Modification of current density profile stabilization of instabilities can require long rf pulses. With nearly 1 MW output power from each gyrotron, diamond windows have made possible rf pulse lengths greater than 2 s to be used. Successful application of CVD diamond technology has required diagnostic measurements of the properties of diamond gyrotron output window assemblies and, in particular, of their thermal response to transmission of microwave beams at high power density. The fundamental diagnostic measurement is infrared imaging of the window during operation.

II. WINDOW CONTAMINATION

The low absorption characteristic of diamond, which makes it ideal for use as a window, also makes this a difficult measurement because the low emissivity of the diamond requires empirical calibration of the setup. In the DIII-D installation, the waveguide transmission line and coupling system are evacuated, so the window must be viewed off-axis through a sapphire viewport in the matching optics unit (MOU). The diamond windows are partly transparent for infrared (IR) radiation from inside the gyrotron. Radiation from this source also will contribute to the observed IR image and will bias the temperature determination. The contribution to the image from this source must be estimated. Three diamond windows with two different thicknesses were measured. The main parameters of the three windows are summarized in Table 1.

All the diamond windows observed to date share the common property that isolated regions of high infrared emission are clearly evident. These are distributed across each of the disks. The spots could arise from points with higher than the local emissivity or of higher than the local temperature or both. Either of these possibilities provides cause for concern. If these hot spots resulted from non-diamond phase inclusions in the bulk material, they might indicate a material degradation at the sites of highly absorbing graphitic phases. If the hot spots were due to impurities on the surfaces of the windows, they might be able to be eliminated by cleaning.

One of the windows mounted on a gyrotron was examined for graphite or other impurities with Raman scattering. It was found that contamination by graphite was present both on the surface and deeper in the lattice. This window was subjected to cleaning by air driven alumina grit. Following this procedure, some, but not all, of the contaminants, presumably those on the surface, had been removed. Raman scattering verified the removal of most of the surface contamination. Blowing on the window surface with dry nitrogen gas resulted in no additional change in the number of hot spots.

III. TEMPERATURE PROFILES

Profiles of the window temperatures taken on diameters across the windows permit quantitative comparisons among the three windows and with ANSYS modeling to be performed. As is clear from Figs 1(a-c), there are
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Fig. 1. The infrared images of the gyrotrons windows differ qualitatively. In (a) the CPI-P2 window infrared image is seen to have a Gaussian character with several pinpoint hot spots. (b) The CPI-P3 window has a much broader temperature, which is nearly flat across the central part of the image. (c) The infrared image has a distinctive hot area in the middle of the window similar to CPI-P2, although the parameters of the diamond disk are similar to the CPI-P3 window.

Fig. 2. Temperature profiles for the three CVD diamond windows measured with an infrared camera are compared with the ANSYS calculation for one of them. The measurements are broader and lower than the model.

IV. CONCLUSIONS

Three different diamond disks in service as output windows for high power gyrotrons were analyzed using an IR camera. Maximum temperatures of the windows for 800 kW transmitted rf power are in rough agreement with theoretical modeling, but temperature profiles differ significantly in details. The window temperatures equilibrate after ~2.5 s at low peak values, which indicates that diamond windows should be able to transmit up to 1 MW rf beams even up to cw operation. Apparent hot spots in the windows apparently do not lead to thermal runaway or other difficulties.

ACKNOWLEDGMENT

This work was supported by the US DOE under Contract No. DE-AC03-99ER54463.