Application of CVD Diamond Window in Infrared Laser Diagnostics for Fusion Plasmas

Y. Kawano, S. Chiba, and A. Inoue

Japan Atomic Energy Research Institute, Naka, Ibaraki 311-0193, Japan

Introduction

As the vacuum window for the infrared CO\textsubscript{2} laser interferometer / polarimeter diagnostic for electron density measurement in the JT-60U tokamak, zinc-selenide (ZnSe) plates were used [1]. (Along the laser beam path, the interferometer and the polarimeter sense $\int n_e \, dl$ and $\int n_e B \, dl$, respectively, where $n_e$ is the electron density, $B$ is the magnetic field.) Since ZnSe is known as a transparent material at a mid-infrared wavelength range of light, especially, it is used as the standard material for various applications around the wavelength of infrared CO\textsubscript{2} laser of $\sim$10 µm. Using ZnSe as a window, however, is often accompanied with certain complaint by its mechanical softness, e.g. sufficiently thick thickness of a ZnSe window is required for vacuum seal, handling and maintenance of ZnSe must be very careful to keep it away from scratch or break.

In the polarimeter, the Faraday rotation by a tokamak plasma is measured. Here, the Faraday rotation component that additionally arises when the laser light passes through windows is a problem. In JT-60U, we have observed the Faraday rotation by vacuum windows (window component) is comparable or in the same order of magnitude to the Faraday rotation by a plasma (plasma component) [2,3]. There are two techniques to remove this window component such as: 1) the calibration of window components against magnetic fields without plasma discharges, 2) the two-color polarimetry to compensate the window component using the different wavelength dependence between the plasma component and the window component [4,5]. However, we should accept certain reduction in data quality by such additional signal treatments.

Diamond Window

We also know that diamond is a widely transparent material from visible to microwave except of certain absorption bands around $\sim$ 5 µm, and the diamond has excellent properties such as excellent mechanical hardness, high heat conductivity, and low thermal expansion. In addition to them, the Verdé\text{t} constant, a coefficient of Faraday rotation at a material, of diamond is $\sim$0.03 min/A (type II diamond) at wavelength of 0.59 µm and this is about seventeen times smaller than the Verdé\text{t} constant of ZnSe $\sim$0.5 min/A. Therefore, diamond...
is a beneficial candidate to use as vacuum windows for optical diagnostics, of course, for infrared laser polarimetry in tokamak devices. Based on the recent development and application of the large sized CVD diamond [6,7], using diamond as the vacuum window of infrared laser diagnostics in tokamak devices has been proposed [8].

**Experiment Results**

In JT-60U, the CVD diamond window has been first applied for infrared laser interferometry and polarimetry. Two vacuum flange sets with two CVD diamond plates (plate size; 55 mm in diameter, 1.2 mm in thickness) in each set have been installed at two tangential ports for the CO\textsubscript{2} laser interferometer / polarimeter, where ZnSe windows (10 mm in thickness) were formally installed. By anti-reflection coating, sufficient transparency per a plate are available such as >98\% at the CO\textsubscript{2} laser wavelength 10.6 μm and >88\% at the visible HeNe laser wavelength 0.633μm, respectively.

Figure 1 shows typical waveforms of the tangential CO\textsubscript{2} laser interferometer / polarimeter with the diamond windows [9]. Here, an identical CO\textsubscript{2} laser beam with wavelength of 10.6 μm has been simultaneously utilized both for interferometry and polarimetry. For a tangentially propagating laser beam, basically, the parallel component of toroidal magnetic field $B_t$ contributes the Faraday rotation. In Fig.1, the toroidal magnetic field coil is energized from about 30 s before the plasma discharge. A plasma discharge begins at $t = 0$ s, where $B_t$ almost reaches its flattop of 3.4 T, and the discharge lasts for 15 s with the plasma current $I_p$ of 1.5 MA at the flattop. The Faraday rotation angle $\alpha$ measured by polarimetry is shown in the second column in Fig. 1. In JT-60U, $\alpha$ is rather small as level of several degree at most. The window component, which should be recognized before and after a plasma discharge according to change in $B_t$, is not clear or negligible as expected due to the combination of low Verdét constant and thin thickness of diamond plates. Line integrated electron density $n_e b_L$ during the plasma discharge
evaluated by polarimetry and interferometry are shown in the third and the fourth columns in Fig. 1, respectively, where $n_{e \text{bar}}$ is the line averaged electron density and $L$ is the laser path length in the plasma ($L = \int dl$). At $t \sim 10.5$ s, $n_{e \text{bar}} \sim 3.7 \times 10^{19}$ m$^{-3}$ and $L \sim 5.9$ m. We have confirmed that there are no problems with diamond windows for electron density measurement by polarimetry and also by interferometry.

A comparison between diamond windows and ZnSe windows for polarimetry is shown in Fig. 2, where measurements were carried out without plasmas but with $B_t$ up to 4 T. Figure 2 (a) shows the temporal behavior of $\alpha$. The clear difference of $\alpha$ is seen between measurement with diamond and that with ZnSe. A tendency of $\alpha$ as a function of $B_t$ is shown in figure 2 (b), and we have confirmed that window component in case of using diamond windows seems insensitive to $B_t$ and it can be negligible. This means that we are free from the window component; hence procedures to remove the window component are not necessary.

**Discussions**

Since polarimetry can be free from the error like “fringe jump”, which is sometimes occurred in interferometry, polarimetry is expected to provide reliable density signal for long pulse and steady state plasma operation. The real-time density feedback control in JT-60U has been started using the improved polarimetry signal with diamond windows and we obtained the preliminary data showing that it works well.
For interferometry with vibration compensation in the two color scheme, using isotope CO₂ lasers has been proposed to extend wavelength separation of the dual CO₂ combination from original 10.6 μm and 9.27 μm. For example, when we introduce $^{14}$C$^{16}$O₂ (12.1 μm) laser and $^{12}$C$^{18}$O₂ (9.0 μm) laser [10], density resolution will be about two times better.

Summary

It has been successful to apply CVD diamond plate as the vacuum window for infrared CO₂ laser interferometry and polarimetry for electron density measurement in a tokamak device. In comparison with to use the conventional zinc-selenide windows, the Faraday rotation component at diamond windows was small as negligible. This resulted in the improvement of the Faraday rotation measurement for a tokamak plasma by polarimetry.

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References