Quasi-optical transmission system for a pulsed ESR system by using a gyrotron as a light source

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Abstract— **In order to realize pulsed ESR measurements by using a gyrotron oscillator. 154 GHz gyrotron output had been successfully sliced to intense and short millimeter wave pulses. A quasi-optical transmission system has been developed to be led these short pulses to ESR measurement probe.**

I. INTRODUCTION

THE electron spin resonance (ESR) spectroscopy is one of the most important methods to investigate microscopic properties in substances [1]. Furthermore, a pulsed ESR method has advantage of measuring relaxation times of electron spins as compared to CW ESR method. One of the most popular pulsed methods is spin echo method, in which subsequent two pulses ($\pi/2$ and π pulses) with a delay time τ are applied to a sample and the echo signal is obtained after another time τ from the end of the second pulse. In general, a pulsed ESR spectroscopy requires a certain pulse duration $\Delta\tau$, then it determines the required strength of the microwave P_{RF} as $\Delta\tau \sim P_{RF}^{-1}$. The higher power means the shorter $\Delta\tau$, which extends the applicability of pulsed ESR methods. To date, the commercial pulsed ESR systems at X-band have been used extensively by researchers. The system with millimeter and/or submillimeter wave region is thought to be more useful. However, its development includes many difficulties in the treatment and development of high power radiation sources. Gyrotron is a high power radiation source in the submillimeter wave region [2-4], which is suitable for the radiation source of a short-pulsed ESR system. The radiation of several kW from a high power gyrotron allows the pulse duration in nanosecond-order. Such system has a potential to develop materials sciences, especially in the subject of substance with short relaxation time.

II. RESULTS

As the high power millimeter wave source, a CW operated sub-THz Gyrotron (Gyrotron FU CW VIIA) has been developed. We examined many candidate modes and finally selected a TE_{02} mode (154 GHz, 150 W). In order to obtain a Gaussian mode electromagnetic wave beam from a TE_{02} mode, a quasi-optical mode converter was developed. A radius of 9 mm beam waist was obtained at the semiconductor shutter system. This liner polarized millimeter wave beam is incident on Si wafers with an incident angle made to a Brewster angle. In order to realize the intense and short excitation millimeter wave pulses by using a Gyrotron output, a high power millimeter wave pulse forming system (PFS) has been developed by using light controlled semiconductor shutters. Figure 1 shows obtained $\pi/2$ and π pulses with the delay time of 60 ns by using a PFS. The delay time between $\pi/2$ and π pulses can be selected any duration.

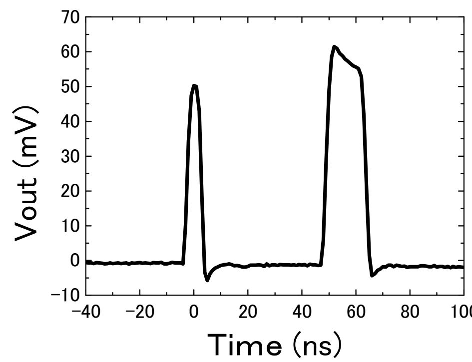

Fig. 1. $\pi/2$ and π pulses with the delay time of 60 ns.

A quasi-optical transmission system has been developed to be led these short pulses to ESR measurement probe. The quasi-optical transmission line has advantages such as a good maintaining liner polarization, low power transmission loss for millimeter and submillimeter wave region. This quasi-optical transmission line is consisted of three characteristic parts. Figure 2 shows a schematic drawing of this quasi-optical transmission system.

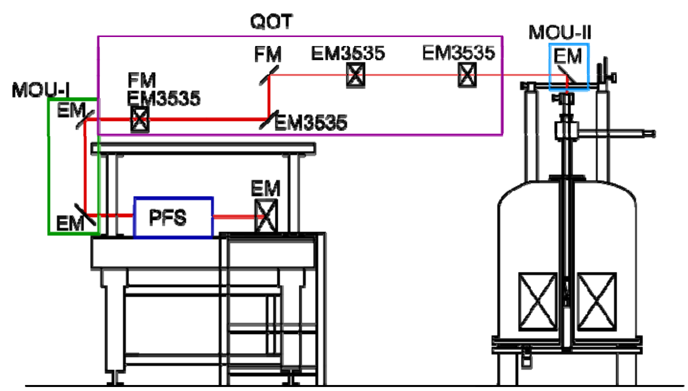

Fig. 2. A schematic drawing of a quasi-optical transmission system for a pulsed ESR system by using a gyrotron as a light source.

The Gaussian beam properties of short pulses from a pulse forming system (PFS) are converted into the form suitable for the long distance transmission in a matching optics unit I (MOU-I). After then, short millimeter pulses are transmitted through a quasi-optical transmission line (QOT) which is consisted of four elliptical mirrors (EM3535) and four flat mirrors (FM) and converted into beam waist size suitable for coupling to the ESR probe which is consisted of a corrugated circular wave guide in a MOU-II.

As well known, the beam width of Gaussian beam is

$$W = W_0\sqrt{1+\left(\frac{\lambda d}{\pi W_0^2}\right)^2}, \quad (1)$$

where W_0 is waist size, λ is wave length, d is distance from beam waist. The relation between the beam width at distance d and the beam waist size W_0 is a trade-off relation. The maximum transmission distance was estimated when the size of the mirror was in 5 x 7 inches used. The beam size was calculated as less than 1/6 to the mirror size. Figure 3 shows a relation between a distance d and a waist size W_0 where λ is 1.95 mm (154 GHz). In this case, the maximum distance d_{max} of 350 mm was obtained with the waist size W_0 of 15 mm. The elliptical mirror EM3535 was design for Gaussian beam with a beam waist 15 mm. The beam can be 700 mm transmitted by using a pair of these mirrors in the QOT.

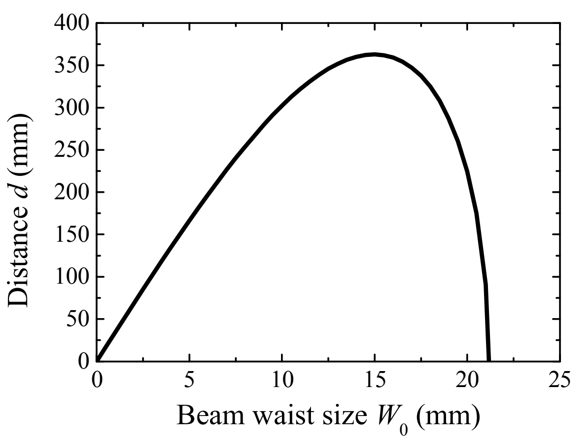

Fig. 3. A relation between a distance d and a waist size W_0 where λ is 1.95 mm (154 GHz).

The MOU-I is consisted of a pair of elliptical mirrors EM9 and EM10 as shown in Fig. 4. The millimeter wave Gaussian beam from PFS was converted to a suitable Gaussian beam for QOT by this pair of elliptical mirrors. Gaussian beam properties of short pulses from a PFS were measured. A waist size of 11.8 mm was obtained. EM9 is located at a position of 390 mm from a beam waist. A distance between EM9 and EM10 is 500 mm. In order to connect to QOT, Gaussian beam from EM10 has a beam waist of 15 mm at a position of 350 mm from EM10. Elliptical mirrors had been designed to satisfy above specification.

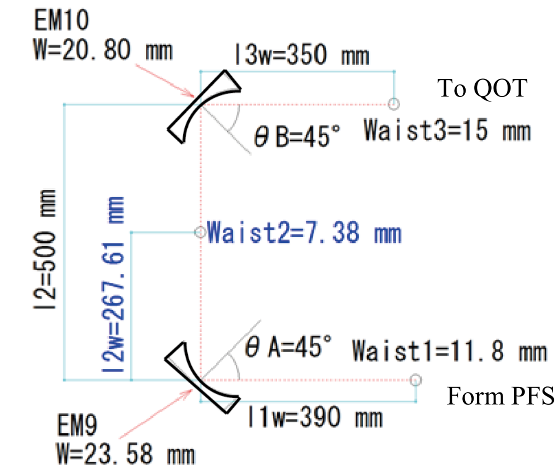

Fig. 4. A schematic drawing of MOU-I

III. SUMMARY

In order to realize pulsed ESR measurements by using a Gyrotron oscillator as a high power millimeter wave source. 154 GHz Gyrotron (Gyrtron FU CW VIIA) had been developed. A Gyrotron output had been successfully sliced to intense and short millimeter wave pulses with arbitrary delay time τ by a light controlled semiconductor shutter system. A quasi-optical transmission system which is consisted of three characteristic parts has been developed to be led these short pulses to ESR measurement probe.

REFERENCES

[1] Charles P. Poole, "Electron Spin Resonance", John Wiley & Sons Inc, 1983.

[2] T. Idehara, I. Ogawa, S. Mitsudo, M. Pereyaslavets, N. Nishida and K. Yoshida, IEEE Transactions on Plasma Science, 27, (1999) 340-354.

[3] S. Mitsudo, T. Higuchi, K. Kanazawa, T. Idehara, I. Ogawa and M. Chiba, J. Phys. Soc. Jpn., Suppl. B, 72, (2003) 172-176.

[4] S. Mitsudo, H. Hoshizuki, T. Idehara and T. Saito, Journal of Physics: Conference Series, 51, (2006) 549-552.