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Progress of High Power Gyrotron for Fusion Devices

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A gyrotron is known as a high-power mm wave source which is used for plasma initiation, plasma heating (electron cyclotron heating: ECH), current drive (ECCD) and plasma stabilization for magnetic confinement plasma devices. The author started the gyrotron development at Japan Atomic Energy Research Institute (National Institutes for Quantum Science and Technology at present) in the 1980's. In the 1980's, the major ECH system employed 60GHz/ 0.2MW class gyrotrons with a pulse duration of ~200ms. But in the 1990's, as the magnetic field strength and the plasma volume of the devices increased, higher frequency, higher power and longer pulsed gyrotrons were expected. For example, 170GHz/1MW in quasi-CW operation was set as a target of gyrotron development for ITER. The research and development of the ITER gyrotron and EC technologies were conducted by Russia, EU, US and Japan. The following are the results achieved by the JA team led by the author.

(1) Achievement of gyrotron efficiency of 50% [1]

The typical power conversion efficiency from the electron beam to the mm-wave is ~30%. 70% of the beam power was consumed at the collector. By employing the depressed collector to the 110GHz gyrotron, the gyrotron efficiency was improved from 30% to 50% at 0.5MW power output in 1994. This brought about the significant reduction of power supply capacity, power deposition to the collector, and cooling system capacity. This depressed collector is a standard technology for the gyrotron, and this is mandatory in particular for the large sized heating system.

(2) Demonstration of 1MW/170GHz [2]

For CW operation, it is necessary to suppress the heat load by the Ohmic loss on the resonator wall at 2kW/cm^2 level. ITER target was the 1MW/170GHz with a long pulse operation. For this purpose, the authors employed very high order oscillation mode TE31,8, and demonstrated 1MW/170GHz oscillation using a short pulse gyrotron in 1995.

(3) Demonstration of long pulse gyrotron with diamond output window [3,4]

The output window had been a critical issue for the long pulse gyrotron because the mm-wave power deposition is large and the temperature increase of the window was so drastic. For example, conventional sapphire double disk window of surface cooling is available only below 0.2MW at 170GHz long pulse operation. The edge cooled diamond window was developed with an EU-JA collaboration [3] and the diamond window was installed to the 170GHz gyrotron. As a result, the stabilization of the window temperature was demonstrated, and opened the way toward the 1MW/CW operation. After the success of the diamond window gyrotron, the ECH system was employed on the JT-60U[5], and electron temperature of 300M Kelvin was obtained using 110GHz gyrotrons with the diamond window and depressed collector.

(4) Achievement of high efficiency 1MW quasi-CW operation at 170GHz [6]

A major obstacle of the gyrotron oscillation at high order mode is the mode competition. By active control of the electron beam parameters during the oscillation, 1MW CW operation was achieved with an unprecedented efficiency of 55% in the so-called hard excitation region. Also, 0.8MW 1hour operation was demonstrated at 57 % efficiency. The maximum efficiency was 60 % at 0.6MW output. The result improved the outlook for using gyrotrons for heating and instability control in future fusion devices.

(5) Multi-Frequency Gyrotron [7,8,9]

The multi-frequency gyrotron was demonstrated by finding the best array of oscillation mode, i.e., TE19,7 at 104GHz, TE25,9 at 137GHz, TE31,11 at 170GHz, TE37,13 at 203GHz. It was found that these modes have the same bounce angle in the mode converter. Consequently, these modes are converted to the Gaussian beam with the same radiation angle, and are outputted through the diamond window. Furthermore, these frequencies are transparent for the diamond window of 1.853mm thickness. By changing the magnetic field and anode voltage of triode electron gun, it was demonstrated ~1MW powers are outputted as a Gaussian beam through the window.

After the activities at QST, the author moved to start-up company Kyoto Fusioneering ltd (KF) which is contributing to the plasma and fusion communities by delivering high power gyrotrons to the world-wide ECH systems of institutes and fusion start-up companies.

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References

[1]K.Sakamoto, et al., Phys.Rev.Lett., 73, 26, p.3532 (1994).
[2] K.Sakamoto, et al., J.Phys.Soc.Jpn, p.1888 (1996).
[3] A.Kasugai, K.Sakamoto, et al., Rev.Sci.Instrum., 69, 2160 (1998).
[4]K.Sakamoto, et al., Rev.Sci.Instrum, 70, p.208 (1999).
[5]Yoshitaka Ikeda, et al., Fusion Sci.Tech.,42, Issue 2-3 p.435 (2002).
[6]K.Sakamoto, et al., Nat.Phys. 3, p.411 (2007).
[7]K.Sakamoto, et al., Nucl. Fusion, 49, 095019 (2009).
[8]K.Kajiwara, et al., Appl. Phys.Express. 4, 126001 (2011).
[9] Ryosuke Ikeda, et al., J.Infrared, Mill., Terahertz Waves, 38, p.531 (2017).