

**STATE-OF-THE-ART OF HIGH POWER GYRO-DEVICES
AND FREE ELECTRON MASERS
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Abstract

Gyrotron oscillators (gyromonotrons) are mainly used as high power millimeter wave sources for electron cyclotron resonance heating (ECRH), electron cyclotron current drive (ECCD), stability control and diagnostics of magnetically confined plasmas for generation of energy by controlled thermonuclear fusion. The maximum pulse length of commercially available 1 MW gyrotrons employing synthetic diamond output windows is 5 s at 110 GHz (CPI and JAERI-TOSHIBA), 12 s at 140 GHz (FZK-CRPP-CEA-TED) and 9 s at 170 GHz (JAERI-TOSHIBA), with efficiencies slightly above 30%. Total efficiencies of 45-50 % have been obtained using single-stage depressed collectors (for energy recovery). The energy world record of 160 MJ (0.89 MW at 180 s pulse length and 140 GHz) at power levels higher than 0.8 MW has been achieved by the European FZK-CRPP-CEA-TED collaboration at FZK where the pulse length restriction to 180 s is due to the HV power supply at $I_{\text{beam}} \approx 40$ A. At lower beam current ($I_{\text{beam}} = 26$ A) it was even possible to obtain 506 MJ (0.54 MW for 937 s). The longest shot lasted for 1300 s at 0.26 MW output power. These very long pulses were limited by a pressure increase in the tube. A maximum output power of 1.2 MW in 4.1 s pulses was generated with the JAERI-TOSHIBA 110 GHz gyrotron. The Russian and the Japan 170 GHz ITER gyrotrons achieved 0.5 MW at 80s pulse duration and 0.3 MW at 60s, respectively. Diagnostic gyrotrons deliver $P_{\text{out}} = 40$ kW with $\tau = 40$ μ s at frequencies up to 650 GHz ($\eta \geq 4\%$). Gyrotron oscillators have also been successfully used in materials processing. Such technological applications require gyrotrons with the following parameters: $f \geq 24$ GHz, $P_{\text{out}} = 10$ -50 kW, CW, $\eta \geq 30\%$. This paper gives an update of the experimental achievements related to the development of high power gyrotron oscillators for long pulse or CW operation and pulsed gyrotrons for plasma diagnostics. In addition, this work gives a short overview of the present development status of coaxial cavity gyrotrons, gyrotrons for technological applications, relativistic gyrotrons, quasi-optical gyrotrons, fast- and slow-wave cyclotron autoresonance masers (CARMs), gyroklystrons, gyro-TWT amplifiers, gyrotwystron amplifiers, gyro-BWO's, gyropeniotrons, magnicons, gyroharmonic converters, free electron masers (FEMs) and of vacuum windows for such high-power mm-wave sources. The highest CW powers produced by gyrotron oscillators, gyroklystrons and FEMs are, respectively, 340 kW (28 GHz), 10 kW (94 GHz) and 36 W (15 GHz). The IR (3.1 μ m) FEL at the Thomas Jefferson National Accelerator Facility obtained a record average power of 2.13 kW with an efficiency of 3.5% (with energy recovery).