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Demonstration of microwave generation by a ferroelectric-cathode tube

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A ferroelectric cathode is employed in a cyclotron-resonance maser (CRM). The CRM oscillator device operates at ~7 GHz, near the cutoff frequency of a hollow cylindrical cavity. The cathode is made of a PLZT 12/65/35 ceramic with high-dielectric constant ($\epsilon_r \sim 4000$). Electrons are extracted from the plasma excited on the cathode surface by ~1 kV short rise-time pulses. The use of ferroelectric cathodes may advance the microwave tube technology for various applications. © *1999 American Institute of Physics.* [S0003-6951(99)03403-8]

Experimental results of microwaves generated by a ferroelectric-cathode based tube are reported. In general, the cathode is a key component in microwave tubes, cyclotron-resonance masers (CRMs), and free electron lasers (FELs). The features of the cathode and its sensitivity to operating conditions are crucial for the performance of the device. Ferroelectric cathodes[1–3] present some attractive features in this regard. They can operate in poor vacuum conditions, at room temperature, and with low voltages. Ferroelectric cathodes do not need heating and pre-activation and they are easy to fabricate and to handle, as compared to thermionic or field-emission cathodes,

In ferroelectric cathodes, electrons are emitted from a surface flash-over plasma caused by electric-field stress of about 10 kV/cm applied to the ceramic in a nanosecond time scale.[1] This electric-field level is lower than needed for field-emission cathodes, and is comparable to that of carbon-fiber emitters.[4] Ferroelectric cathodes produce current densities up to 100 A/cm^2. Such cathodes were proposed as electron-beam sources for free-electron electromagnetic-wave generators.[2,3]

Radiation bursts in a ferroelectric-cathode slow-wave device were observed in our previous experiment.[5] In the present oscillator experiment, the ferroelectric cathode is employed in a CRM scheme. This device, operating in a gyrotron mode[6] near cutoff, tolerates the electron energy spread, and is characterized by its high gain.

A schematic of the CRM experimental device is shown in Fig. 1. A cylindrical cavity, 60 cm long and 2.6 cm diameter, is formed by the electron entrance grid and by a partial mirror at the other end. An accelerating direct voltage up to 9 kV is applied to the cavity. The spacing of the accelerating gap is 2.5 cm in order to avoid a voltage breakdown during the current pulse. The partial mirror, a disk with a hole in its center, enables the passage of the electron-beam and the coupling of the microwave output. The cyclotron orbits of the electrons along the cavity are induced and confined by the solenoid magnetic field. The electron current is dumped by an electrically isolated collector and measured by a Rogovsky coil.

The microwave output is coupled out through a WR90 adapter and analyzed by a diagnostic system, which consists of a bandpass filter and a calibrated crystal detector. The experimental setup and operating parameters resemble our previous CRM experiment with a carbon-fiber cathode.[4]

The planar-diode electron gun is illustrated in Fig. 2. The cathode is made of a PLZT 12/65/35 ceramic plate (~1 cm^2 area and 1 mm thickness). The ceramic dielectric constant is $\epsilon_r \sim 4000$. A conductive silver paint contact (6 mm diameter) is deposited on the rear surface of the ceramic plate. A brass washer is glued to the emitting surface as a ring electrode. Its external and internal diameters, and thickness, are 6, 3.4, and 0.2 mm, respectively. A stainless steel grid (52 μm wire diameter, 460 μm period) is mounted directly on the brass washer front providing a volume for the free plasma expansion. A positive trigger voltage pulse of ~1 kV with a rise time of tens of nanoseconds is applied between the rear contact and the grounded washer. Both negative and positive pulses trigger the plasma generation, but the electron energy spread is smaller for positive pulses.[7]

Typical current and microwave output detector traces are shown in Figs. 3(a) and 3(b), respectively. Currents of 0.4 A and ~1 μs pulse width are measured at the collector. The

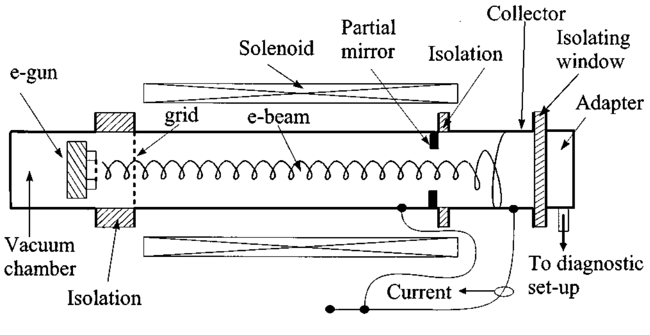

FIG. 1. The cyclotron-resonance maser device.

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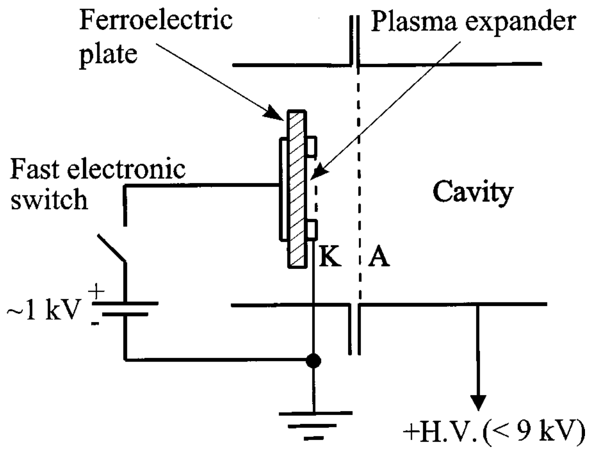

FIG. 2. A ferroelectric-cathode electron gun.

microwave output-power exceeds 25 W in many shots when the electron beam is accelerated to 9 kV. The electronic efficiency (i.e., the ratio between the microwave power and the electron-beam power) exceeds 1%.

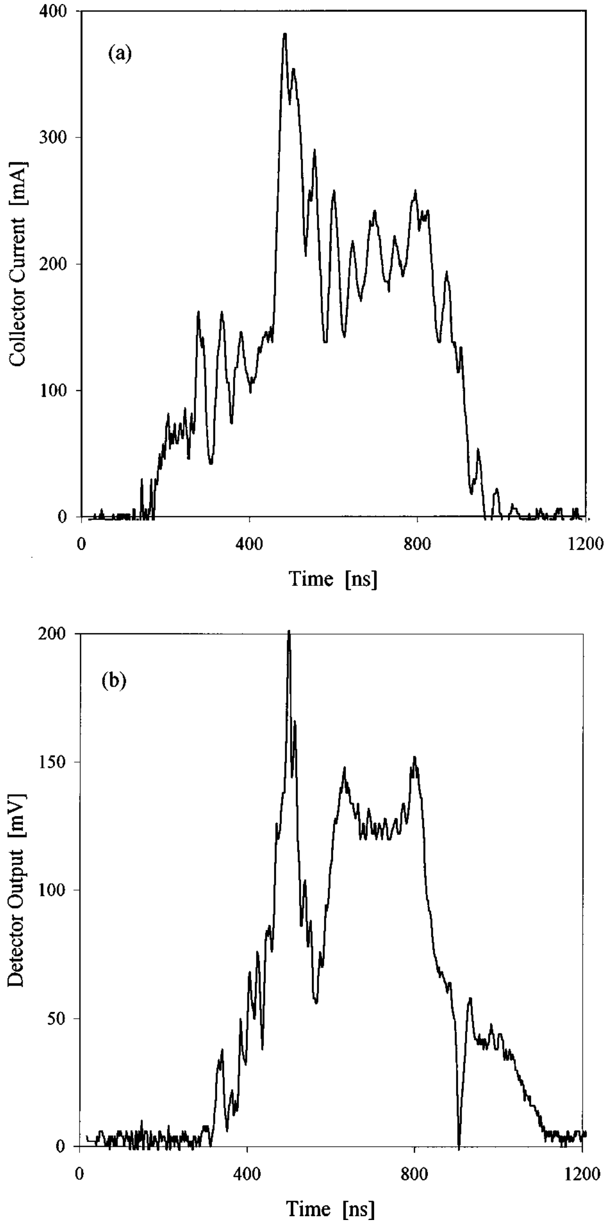

FIG. 3. Electron current (a) and microwave detector output (b).

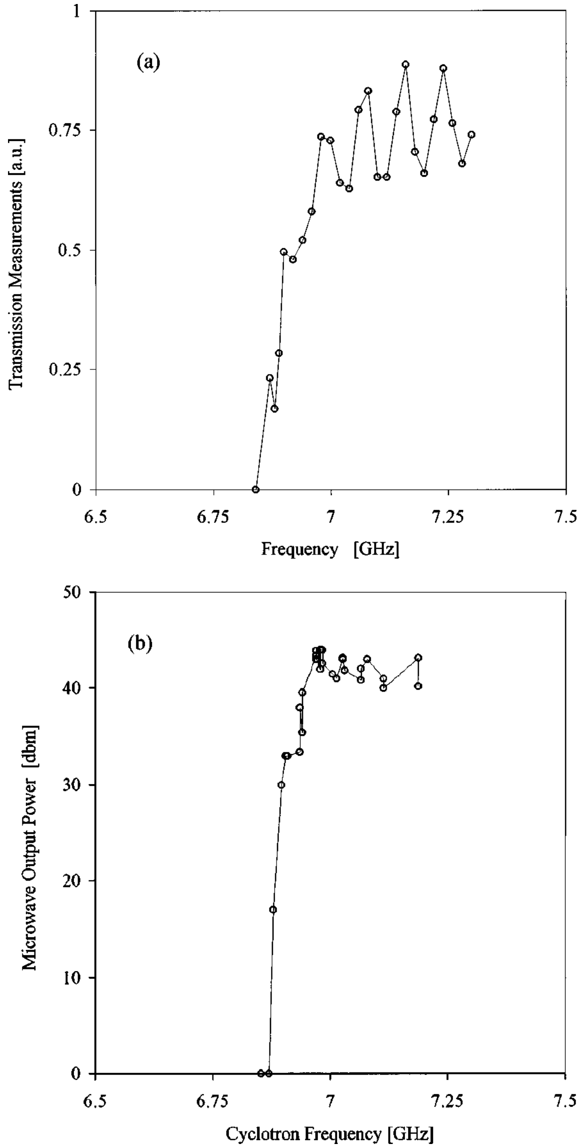

FIG. 4. (a) The waveguide transmission measurements. (b) The CRM output power vs the cyclotron frequency determined by B_0.

The waveguide cutoff frequency, $f_{\rm co}=6.9\,\rm GHz$, is found by transmission measurements shown in Fig. 4(a). The CRM interaction mechanism is verified by measuring the microwave output power as a function of the solenoid magnetic field, B_0. The latter determines the electron cyclotron angular-frequency $\omega_c \cong eB_0/m$. The CRM operating condition near cutoff is $\omega \approx \omega_c$, where ω is the *em* radiation angular frequency. Consequently, the CRM operating condition should be $\omega \approx \omega_c \geqslant 2\pi f_{\rm co}$, or $B_0 \geqslant 2\pi m f_{\rm co}/e$. This operating condition is verified experimentally as evidence of the CRM type of interaction. As is seen clearly in Fig. 4(b), the microwave output is obtained only when the cyclotron frequency is larger than the waveguide cutoff frequency.

The results presented in this letter show CRM operation with a ferroelectric cathode and, to our knowledge, the first published report on a microwave tube operating with a ferroelectric cathode in general. This experiment is followed in our laboratory by studies of new CRM schemes in which unique features of ferroelectric cathode can be utilized exclusively. Ferroelectric cathodes can be used in a low repetition-rate or single-shot compact CRMs. They can be easily fabricated in various shapes for producing specified cross-sectional profiles of the electron beams, including large two-dimensional (2D) electron-beam arrays for multibeam devices proposed recently.[8]

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