OBSERVATION OF OPERATING MODE IN RAMAN FREE ELECTRON LASERS*

Bibo Feng[1], Zaitong Lu, and Lifeng Zhang
Shanghai Institute of Optics and Fine Mechanics, Shanghai, China

Abstract

The method of microwave-induced gas breakdown to diagnose the operating mode structure in a nanosecond-pulse high-power Raman free electron laser is presented. Modes of low azimuthal and radial index, such as TE_{11} or TM_{01}, are observed in the Raman free electron laser experiments. Occasionally, some mixed mode photographs of the output wave are also obtained, such as the sum of TE_{11} and TE_{01}. In the region of gyroresonance and higher $\beta_\perp$, the modes with the high index for electron cyclotron maser are obtained; combined low- and high-index modes are also observed in the same experimental parameters. The results of experimental observation are discussed and a prediction of mode analysis is made.

I. Introduction

Raman free electron lasers(FELs) operating in a combined axial guide magnetic field and a transverse wiggler field have been researched theoretically and experimentally for many years. We carried out a series of Raman FEL experiments with a low emittance electron beam (0.4-0.5 MeV), corresponding the output radiation wavelength in millimeter wave region[1-4]. In these experiments, a waveguide must be employed to confine and propagate the output radiation. Therefore, a transverse radiation mode, where the frequency is above the waveguide cut-off frequency, can propagate in the waveguide. In this interaction region, mode competition results in establishing a radiation mode and suppressing the gain of other modes. The mode observation would be benefit for studying the interaction mechanism in Raman FELs and discovering the effects of waveguide mode.

In addition, in the Raman FEL interaction region, the electron beam current is near a kiloampere. To propagate such a high-current beam through a wiggler region, a guide magnetic field should be employed to compensate the defocusing force arising from the repulsion of electrons. When the guide magnetic field is used in an FEL system, it is sure that the FEL interaction is enhanced. At the same time, the cyclotron interaction may also be contaminated, especially in region of gyroresonance, where electron cyclotron frequency resulting from the guide field is closed to the wiggler frequency and the electron transverse velocity is larger.

In the view of these problems, it is important to observe the transverse structure of the radiation for studying the radiation mechanism and its properties.

II.Measurement method and experimental setup

When a pulsed high power microwave (or millimeter wave) propagates through a low pressure gas cell, the microwave induced gas breakdown may occur. This phenomenon primarily depends on the local electric field, and is also concerned with the property of gas, pressure, pulse duration, repetition and wavelength of the microwave, etc. According to the principle of microwave-induced gas breakdown, we can observe the radiation wave length and operating modes of the pulsed high-power millimeter-wave FEL.

An empirical formula for the threshold of microwave breakdown electric field E_b can be found as[5]

$$E_b = AP\left[1 + \left(\frac{a}{P\lambda}\right)^2\right]^{\frac{1}{2}}, \qquad (1)$$

where P is the gas pressure in Torrs and λ is microwave wavelength in meters. Values of A and a depend on the gas property, for example, A=3000v/m Torr, a=0.9 torr m for nitrogen under certain waveband, pulse duration, and repetition. The microwave-induced gas breakdown characteristics for some gases or mixed gases are shown in Fig.1, where the lowest gas breakdown electric field for the mixed gases is much less than the pure gases.

In our experiments, average electric field 1.8kV/cm at the laser output window is estimated considering the pulsed radiation power 5-MW in

* This work was supported under National Funds of Natural Science of China.
1 Present address: Laboratory of Nuclear Science, Tohoku University, Sendai 982, Japan

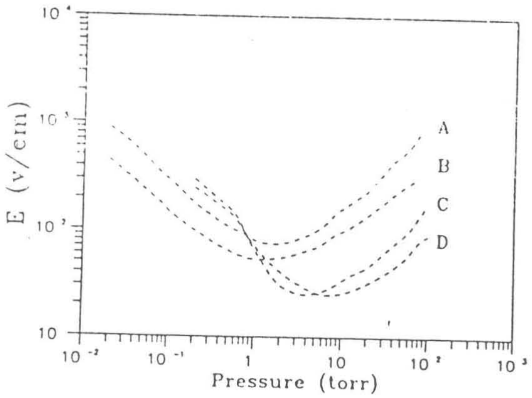

Fig.1.Breakdown electric field versus gas pressure for variant gas or mixed gas. A: Hydrogen, B: Argon, C: Helium + 1% Argon, D: Neon + 1% Argon.

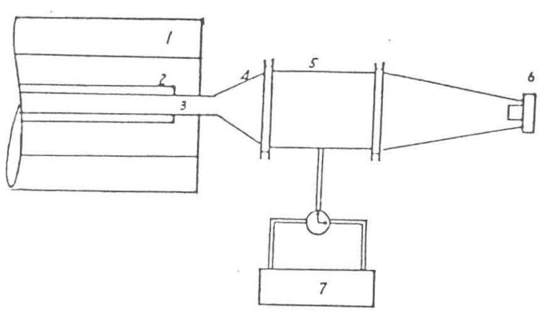

Fig.2,Schematic diagram of experimental system for observing operating mode in a Raman free electron laser. 1, guide magnet, 2, wiggler magnet, 3, drift tube, 4, output horn, 5, low pressure gas chamber, 6,camera, 7, pumping and filling gas system.

the output window, where the output horn diameter is 54 mm. Therefore, the satisfactory gas breakdown photographs are obtained in our Raman FEL experimental device with definite properties, pressures of gases, and component rates of mixed gases. The schematic diagram of the experimental system for the mode observation with the principle of microwave-induced gas breakdown is shown in Fig.2. The cylindrical low pressure gas cell (a hermetically sealed system), which is closed to the window of the output horn, can be pumped out and filled with different gases.

Suitable gases and their component rate in the cell are selected, and an electric field with enough high strength can break down the gases. While the pulsed high-power millimeter- wave radiation transmits into the cell, the glow discharge occurs and the bright spot pattern is shown in photographs. In the experiments, Ar and Ne mixed gases are used as the microwave breakdown media with the gas component rate 1:100(Ar:Ne) and the total pressure < 20 Torr.

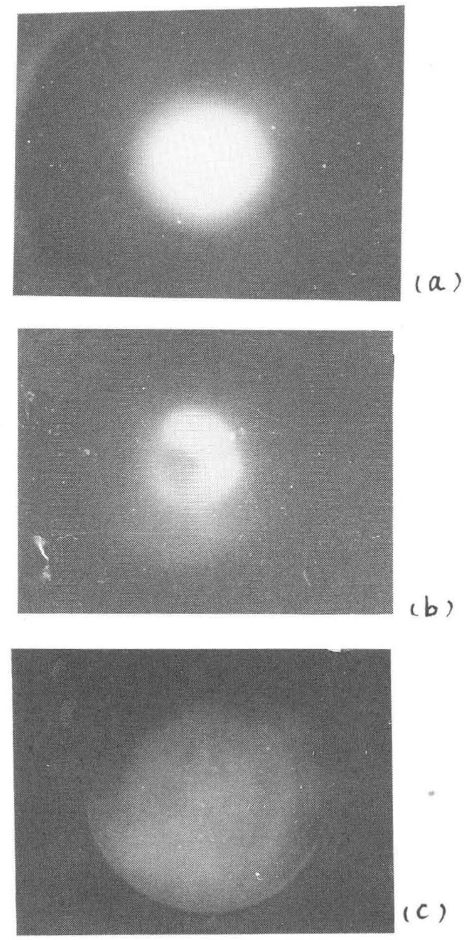

Fig.3, Photographs of microwave-induced gas breakdown for illustrating the mode observation, (a) B_0=9900G, (b) B_0=8250 G, (c) B_0=8250G.

IV. Results and discussion

The transverse mode observation experiments were made with variant magnetic field condition. The results are shown in Fig.3 and 4. Figure 3 shows the mode patterns, which are in response to the Raman FEL operating condition in the ungyroresonance region. These photographs of microwave-induced gas breakdown show TE_{11} or TM_{01}, for example, in Fig.3(a),(b). Photographs of other multimode structure photographs are also observed in Fig.3(c), including the low order mode and TE_{01} mode.

Reference 6 predicted that it is impossible to exist the TE_{01} mode in the FEL radiation. However, the simulation results in Ref[7] indicate that the generated radiation is dominated by the TE_{11} mode in the case of an axis-centered beam, and the TE_{01} mode could be excited through a nonlinear effect at later stage of the radiation growth. Furthermore, if the beam center is off axis, both TE_{11} and TE_{01} mode are excited with comparable growth rate and

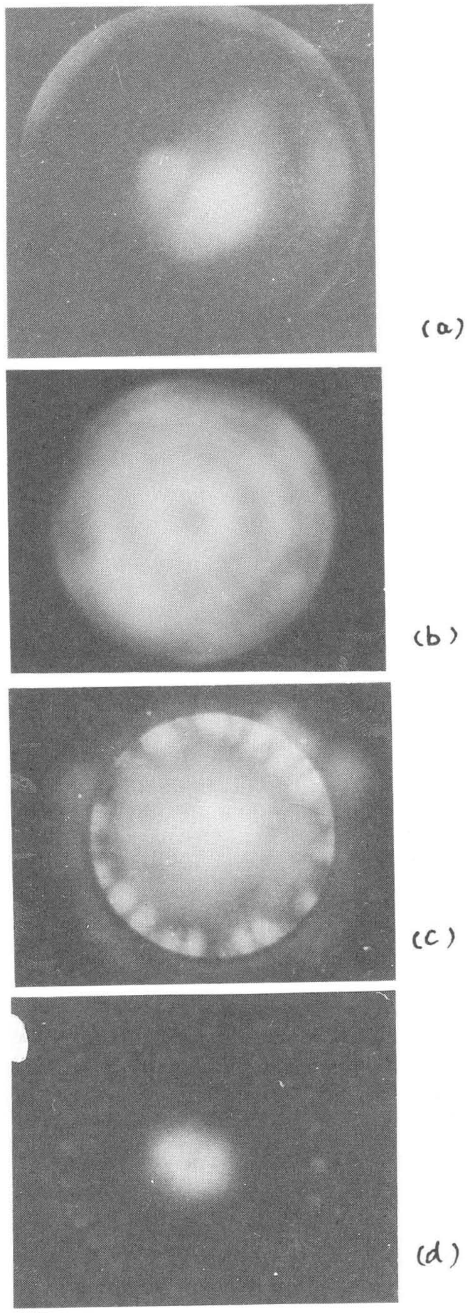

Fig.4, Photographs of microwave-induced gas breakdown for illustrating the mode observation, B_0=7150 G, $\beta_\perp$=0.58.

comparable amplitude. Thus, it is possible to get the TE_{01} mode in our experiments. Referring to theoretical analyses of the mode, it is unreasonable to present the TE_{01} mode for our FEL operating parameters, but primary or second harmonic cyclotron radiation with a reasonable radiation frequency should be possible.

As mentioned, even if the Raman FEL is operating in the ungyroresonance region, there is the case where both the FEL and cyclotron maser are present. We can also obtain the laser radiation frequency 40.5 GHz and 40.3 GHz for Fig.3 (a) and (b), respectively, in responsible experimental cases.

With the same experimental magnetic parameters of the guide field B_0~7150 G and the wiggler field B_w ~ 1820 G, four different mode patterns were observed as in Fig.4, where Fig.4(a) and (b) display TE_{11} and TM_{03} modes, respectively; the high-order cavity modes and multimode structure were also observed in Fig. 4(d) and Fig. 4(c).

Noted that the operating parameters are near gyroresonance regime and the electron transverse velocity $\beta_\perp$ is higher, the output radiation seems more likely to be the cyclotron maser radiations. It is obvious that there is intense mode competition in cyclotron interaction, which is beyond the scope of this paper and so is not discussed in detail hear.

The transverse mode measuring method of high-power microwave-pulse-induced gas-breakdown in Raman FEL has many advantages; for example, the measurement system is simple and the measured results are directly shown in photographs. Further experiments will be improved to perform the synchronous measurement of both wavelength and the transverse mode. Moveover, some microwave absorbing materials need to be placed in the low pressure cell to obtain more clear photographs of gas breakdown pattern.

References

[1], Chucheng, Lu Zaitong, Shi Ruigen and Wang Zhijiang, "Parametric study of Raman free electron laser", Scientia Sinica A,(3)379(1988).

[2], Lu Zaitong, Zhang Lifen, Chen Jizhong, Shi Ruigen and Wang Zhijiang, "Experimental study of a Raman free electron laser with 1.19 m interaction length", ACTA Optica Sinica, **V.9**, (9)780(1989).

[3], Lu Zaitong, Zhang Lifen, Wang Mingchang and Wang Zhijiang, "Spectral measurement of a Raman free electron laser",Chinese Journal of Laser, **V.18**,(12)881(1991).

[4], Bibo Feng, Zaitong Lu, and Mingchang Wang,"Investigation of Raman free electron laser with a bifilar helical small-period wiggler",IEEE J. Quantum Electron. (to be published);

[5], A. D.Mcdonald, "Microwave Breakdown in Gases", p.160, 1966.

[6], H.P. Freund, S.Johnston, and P.Sprangle, "Three-dimensional theory of free electron laser with an axial guide field", IEEE J. Quantum Electr., **QE-19**, (3)322(1983).

[7], A.T. Lin and Chih-chien Lin, "Mode competition in Raman free electron lasers", Nuclear Instruments and Methods in Physics Research, **A250**, 373(1986).