COMPACT TERAHERTZ FREE-ELECTRON LASER AS A USERS FACILITY

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Abstract

We have developed a laboratory-scale users facility with a compact terahertz (THz) free electron laser (FEL). The FEL driven by a magnetron-based microtron operates in the wavelength range of 100-1200 μm, which corresponds to the frequency of 0.3-3 THz. The peak power of the FEL is 1 kW and the spectral width of the radiation is 0.3-1.0 cm^{-1}. The microtron accelerator has been upgraded to drive stable operation of the FEL by stabilizing current and bunch repetition rate of the electron beam. The FEL can be operated during several hours without further adjustment and the fluctuation of the pulse energy during the period is less than 10% in rms value. We could measure the surface electromagnetic wave (SEW) of various materials including nano-scale thin films. We are also preparing THz imaging systems by 2-D scanning for high resolution and by the electro-optic method for single pulse capturing. The main results on the FEL and its applications are presented in this report.

INTRODUCTION

There are increasing demands on advanced infrared (IR) and far infrared (FIR) radiation sources for the applications on biomedical research, solid-state physics, gas spectroscopy, and so on [1-4]. The newly constructing synchrotron IR/FIR beamlines [5, 6] and free electron lasers [7,8] are also based on the demands. Table-top FIR sources generated by conventional lasers have been developed and used for the applications. Inexpensive and compact FIR FEL [8-10] can play the important role of encouraging the FIR applications due to its higher power and spectral brightness than the table-top sources.

We have developed a compact FIR FEL driven by a magnetron-based microtron [9] as shown in Fig. 1. We could extend the FEL wavelength range of 100-1000 μm with the variable-energy microtron and we could construct a users experimental stage for the wavelength of 100-300 μm [10,11]. The wavelength range of the FEL is shown in the Fig. 2. The FEL and FIR experimental setup are placed in a laboratory with the area of 40 m^2. The microtron accelerator of the FEL has been stabilized in its current and RF frequency, which provides stable operation of the FEL without further adjustment during several hours. The FIR radiation at the experimental stage is well collimated and the diverging angle of the radiation is less than 1 mrad at the stage. We could measure the absorption and reflectance signal from samples with the fluctuation of ~1% by monitoring the pulse energy of the FEL beam. The S/N ratio of the single pulse measurement could be more than 10^7 by using a liquid-helium cooled Ge:Ga detector. With the system we could measure preliminary data of FIR imaging with a leaf and spectrum of liquid and vapour water. The optical characteristics of nano-thickness thin films were also measured by exciting the surface electromagnetic wave. The application results are reported in this paper with brief description of the FEL system.

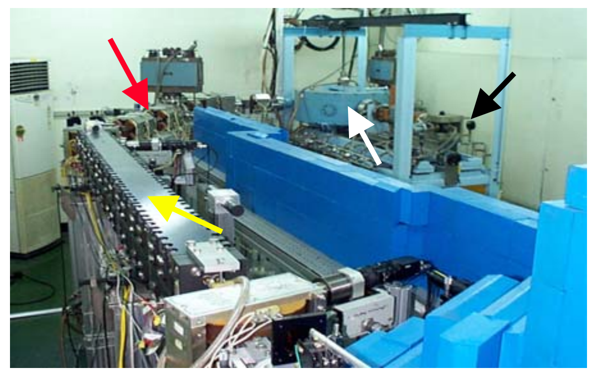

Figure 1: Photograph of a compact terahertz free electron laser driven by a magnetron-based microtron. The length of the undulator is 2 m and a high voltage modulator for RF generator is located under the microtron and RF system.

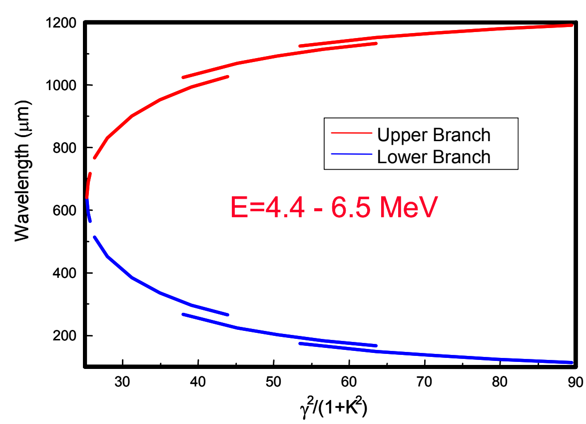

Figure 2: Wavelength range of the THz FEL depending on the energy of the electron beam from the microtron.

SYSTEM STABILIZATION

The microtron accelerator with a RF generator of magnetron is a simple and inexpensive driver for compact FIR FEL. However the electron dynamics in the microtron is not so simple due to the strong coupling between the magnetron and an accelerating cavity having an electron gun inside. Main parameters of the gun, RF generator and cavity can not be independently controlled to get the optimal condition of the electron beam. We have investigated the accelerator by numerical simulation for the transient state of the coupled magnetron-microtron cavity system. The result shows a good agreement with experiments and we could find optimal working parameters of the beam current and RF frequency for the stable operation of the FEL. The main results are shown in Ref. [12].

The FIR radiation is transported by a relay optics in a vacuum channel and the focal length of the relay optics is approximately 10 m from a collimating lens near an output coupler mirror of the FEL resonator. The focal point is set between the experimental tables for applications. Fig. 3 shows measured spatial distribution of the FIR radiation at the experimental tables. The distances in the figure are values between the measured points and the beam splitter. We can see the focal point of the radiation is located between 1.5 and 2 m from the beam splitter and the minimum spot size is 7 mm in FWHM. We could get the high accuracy of the FIR measurements by improving the driver accelerator and diagnostics.

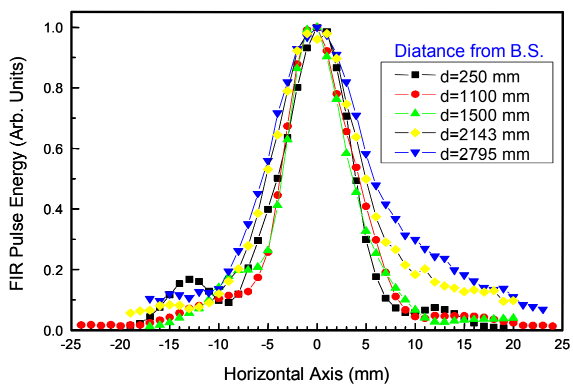

Figure 3: Measured spatial distribution of the FIR radiation at the experimental tables of the facility. The distances noted in the figure are values between the measured points and the beam splitter for pulse energy monitoring.

Additionally we could stabilize the pulse-to-pulse current of the electron beam by the feedback control of the emission current from the gun. With the stabilization we could operate the accelerator during several hours without a breakdown inside the cavity [12]. The fluctuation of the macropulse current was less than 1% during our observation for several hours. The fluctuation of the macropulse energy of the FEL was measured to be less than 10% during the time.

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PRELIMINARY RESULTS OF APPLICATIONS

We have measured the preliminary data of spectral absorption on liquid and vapour water. The absorption coefficient of the liquid water at the wavelength near 110 μm was measured to be approximately 400 cm^{-1} and the result agrees well with previous measurement [14]. Now the main part of the experimental stage is open to air and we want to know the absorption characteristics of air, mainly effect of water vapour, in the FIR wavelength range. Additionally we also want to use the spectral data to know the absolute value of the FIR wavelength with high accuracy.

We have constructed a FIR imaging system by scanning with a small aperture. One-dimensional scanning with an aperture of 0.1 mm was tested with a bamboo leaf and the result was compared with a scanned intensity profile of the photograph, which is shown in upper part of Fig. 4 (b). The photograph of the leaf is shown in Fig. 4 (a) with the same scale of the scanned profiles in Fig. 4 (b). The both profiles represent well the periodic structure of the leaf having the period of 0.1-0.2 mm. The profiles should be in the relation of inverse image due to the extremely big difference in the absorption coefficients of liquid water for the wavelength ranges. However we can not see the strong correlation between the profiles, which might show the usefulness of the FIR imaging.

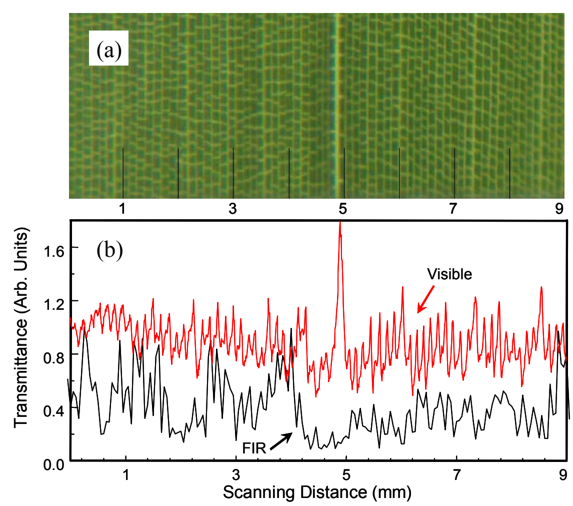
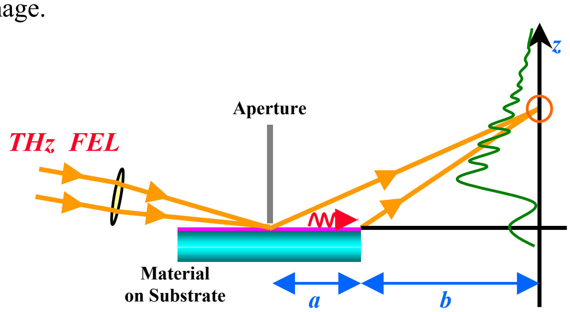


Figure 4: One-dimensional FIR scanning with an aperture of 0.1 mm performed with a bamboo leaf. The result was compared with a scanned intensity profile of the photograph shown in upper part of Fig. 4 (b). The photograph of the leaf is shown in Fig. 4 (a) with the same scale of the scanned profiles in Fig. 4 (b).

We are constructing a fast imaging system with a single micropulse of the FEL beam by using the electro-optic (EO) detection and switching method. The linearly polarized visible or IR laser beam is collinearly incident to the EO crystal with the FIR beam. The image of the FIR beam is transferred to the visible or IR laser beam.

And we will use an intensified CCD camera to capture the image.



$$Re\,\Omega \cdot a + \sqrt{b^2 + z^2} + \Delta\varphi \cdot \lambda - \sqrt{(b+a)^2 + z^2} = m\lambda$$

Figure 5: Schematics of thin film SEW measurement.

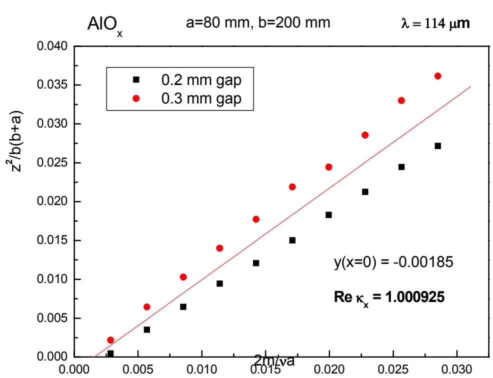


Figure 6: Measured optical constants of AlO_2 thin film having the thickness of 3 nm.

The schematics of surface electromagnetic wave (SEW) experiment to investigate the optical constants of thin films are shown in Fig. 5. And the measured result of the optical constants of AlO_2 is shown in Fig. 6.

CONCLUSION

We have developed a laboratory-scale users facility by using a compact FIR FEL. We hope the system could be used for advanced experiments on FIR wavelength range. The efficiency of the FEL from the electron energy to the FIR radiation is less than 0.1% due to the low energy spread of the electron beam and big slippage during the FEL oscillation. We are considering a tapered undulator to increase the efficiency. We will analyze the possibility with the theoretical calculation. The compact FEL with the efficiency of more than several percentages can generate the FIR radiation with the average power of 1 W.

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REFERENCES

[1] B.M. Fischer *et al.*, Phys. Med. Biol. 47, (2002) 3807.

[2] M. Walther *et al.*, Chem. Phys. Lett. 332, (2000) 389.

[3] T. Dekorsy *et al.*V.A. Yakovlev, W. Seidel, M. Helm, and F. Keilmann, Phys. Rev. Lett. 90, (2003) 055508.

[4] G. Lupke *et al.*, Phys. Rev. Lett. 88, (2002) 135501.

[5] M. Abo-Bakr *et al.*, Phys. Rev. Lett. 88, (2003) 254801.

[6] F. Sannibale *et al.*, "CIRCE: a dedicated storage ring for Far-IR THz coherent synchrotron radiation", International Workshop on Infrared Microscopy and Spectroscopy with Accelerator-Based Sources, July 2003, Lake Tahoe, CA, USA.

[7] D. Douglas *et al.*, "A 10 kW IR FEL design for Jefferson Lab.", Proceedings of the 2001 Particle Accelerator Conference, Chicago, IL, USA.

[8] A. Doria *et al.*, "CATS: a compact free electron source in the THz region", International Workshop on Infrared Microscopy and Spectroscopy with Accelerator-Based Sources, July 2003, Lake Tahoe, CA, USA.

[9] Y.U. Jeong, *et al.*, Nucl. Instr. and Meth. A 475 (2001) 47.

[10] Y.U. Jeong, *et al.*, Nucl. Instr. & Meth. A 507 (2003) 125.

[11] G.M. Kazakevitch, *et al.*, Nucl. Instr. & Meth. A 507 (2003) 146.

[12] G. Kazakevich *et al.*, "Stabilization of the microtron-injector for a wide-band compact FIR FEL", Presented at the 25th International FEL Conference + and 10th FEL Users Workshop, Tsukuba, Japan, Sep. 2002.

[13] N. Nishimori *et al.*, Phys. Rev. Lett. 86 (2001) 5707.

[14] J.K. Vij and F. Hufnagel, Chem. Phys. Lett. 155 (1989) 153