DESIGN STUDY ON HIGH- TC SUPERCONDUCTING MICRO-UNDULATOR

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Abstract

Design study on a new type of high critical temperature (T_C) superconducting micro-undulator was carried out. In this work, we introduce staggered array type micro-undulator using high T_C superconducting material. Transverse magnetic field was measured with $YBa_2Cu_3O_7$ bulk superconductors at 77 K. The maximum transverse magnetic field strength was about 0.5 mT, when longitudinal magnetic field of the strength in the range of 2 mT to 15 mT was applied.

INTRODUCTION

A micro-undulator or short period undulator will be a useful device for a compact FEL device and/or a short wavelength FEL.

When a high energy electron beam moves in the periodic magnetic field, resonant wavelength emitted from the undulator λ_R is written by following well-known equations.

$$\lambda_R \cong \frac{\lambda_u}{2\gamma^2}\left(1+\frac{K^2}{2}\right) \qquad (1)$$

$$K = \frac{e \cdot B_0 \cdot \lambda_u}{2\pi \cdot m_0 c} \approx 93.36 B_0 \cdot \lambda_u \qquad (2)$$

Here, λ_u is the undulator period and γ is Lorentz factor, K is the undulator parameter, e is the charge of the electron, B_0 is the maximum transverse magnetic field strength of the undulator, m_0 is the electron mass and c is the speed of light. To obtain shorter wavelength radiation, undulator period should be short or electron energy should be high. Thus, if the λ_u is limited, high energy electron beam is required for short wavelength FEL such as X-FEL. In other word, if a short period undulator realizes, high energy electron is not required. Moreover since the FEL gain increases as the number of period of undulator increases, the short period undulator will have advantage.

However, if we need K=1 for short period undulator of 5 mm, B_0 should be almost 2 T. Thus, to realize micro undulator or short period undulator, strong transverse magnetic field is required.

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HIGH TC SUPERCONDUCTING UNDULATOR

Design of high T_C superconducting undulator

To obtain transverse periodic magnetic field in a short period, we introduce following micro-undulator as shown in Fig. 1.

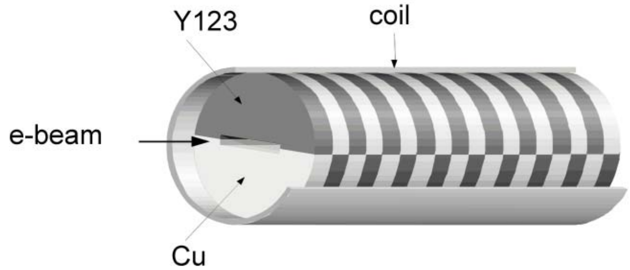

Fig. 1. Conceptual drawing of the high T_C SC undulator.

High Tc bulk superconducting materials are stacked in the solenoid. First, these superconducting pieces are cooled down below the critical temperature T_C. Then, a solenoid field is applied. As a result, density modulation of the magnetic field is produced, and thus the periodic transverse magnetic field is generated on the electron beam axis. To realize shorter period, in vacuum structure is planned. If we can control the magnetic field precisely, extreme good electron beam confinement can be realized [1].

If a perfect Meissner state is kept in a high magnetic field strength of several T, excellent performance will be realized. Unfortunately, Meissner region is typically limited below the lower critical field of several hundred mT, but superconductivity is left up to the higher critical field of 100 T. Thus we tried to measure the transverse magnetic field above lower critical field.

Expected performance

We have estimated performance of the undulator for following applications.

1) Compact IR device
2) Ultra short wavelength FEL
3) THz device

If such short period undulator with high transverse magnetic field is applied for 1) compact IR FEL device, required electron energy will be less than 15 MeV as shown in Fig. 2. Therefore a very compact IR system can be designed.

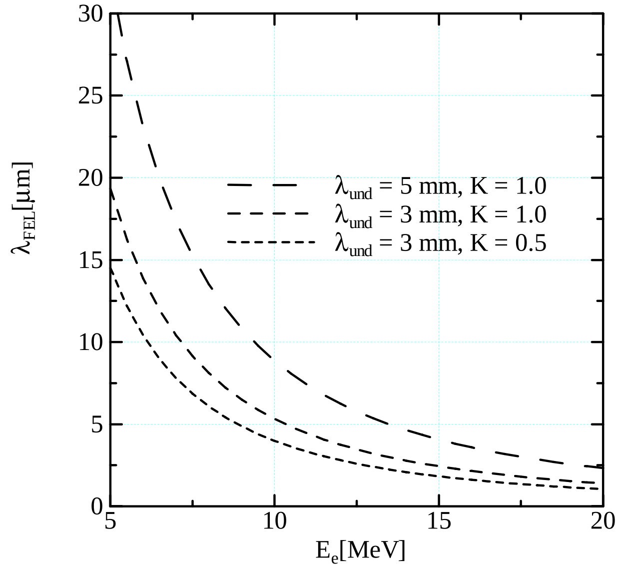

Fig. 2. Expected wavelength for short period undulator with several tenth MeV electron beam.

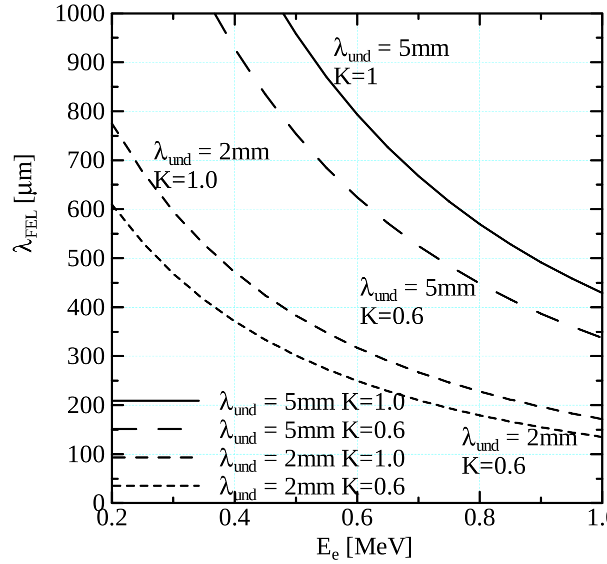

Fig. 4. Expected wavelength for THz device.

For application to 2) ultra short wavelength FEL, the device is also fascinating as shown in Fig. 3. The FEL wavelength of 1 Å will be achieved with 3 GeV electron beam. It is expected that the whole system could be compact, because the length of the undulator and the accelerator will be shortened compared to present configurations of such X-FEL systems.

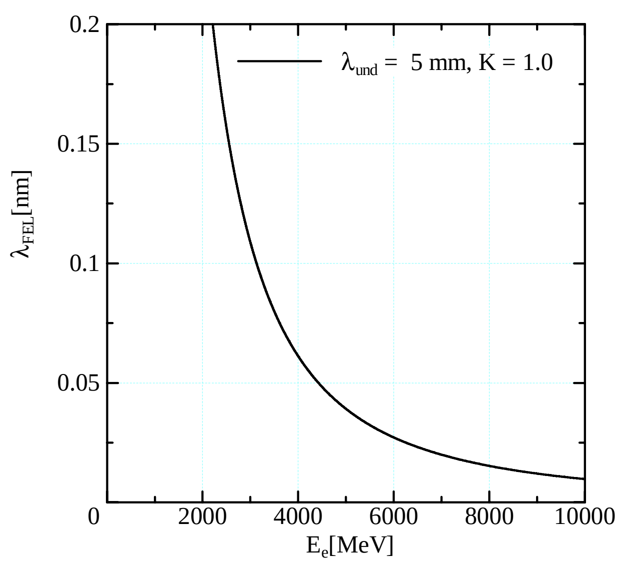

Fig.3. Expected wavelength for GeV class electron beam.

A simple configuration consisted of an electron injector and the proposed micro-undulator will provide 3) the THz radiation as shown in Fig. 4. This system could generate an intense THz radiation with a variety of operation mode, in CW, because we can use a CW electron injector.

EXPERIMENT

To confirm the proposed micro-undulator, a preliminary experiment has been performed. In this work, $YBa_2Cu_3O_7$ (YBCO) ceramic was selected as the high T_C superconducting materials, because it is easy to obtain, and Tc is higher than the boiling point of liquid nitrogen. Presintered YBCO powder made by Furuuchi Chemical Corporation was used for sample fabrication. Test peaces were made as following. The powder was pressed into disks and sintered in an oxygen-containing atmosphere for 12 hours at a temperature of 900° C, and annealed for 48 hours at a temperature of 500° C. Diameter of the test pieces was 27 mm and thickness was 2.5 mm. Superconductivity of the test pieces were checked by the Meisner effect and pinning effect using small permanent magnet on the cooled test material. Schematic drawing of the superconducting test piece is shown in Fig. 6.

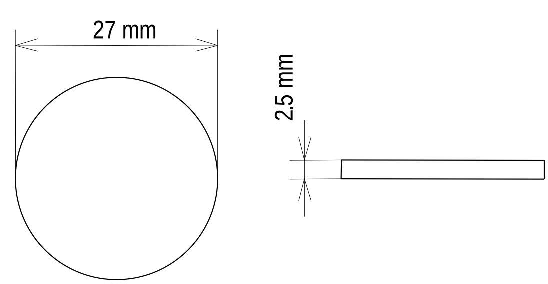

Fig. 5 Schematic drawing of the YBCO test piece.

Transverse magnetic field produced by the cooled ceramics was measured with a dipole magnet and a 3-Channel Gaussmeter Model 460, manufactured by Lake Shore Cryotronics, inc. Experimental setup is shown in Fig. 6.

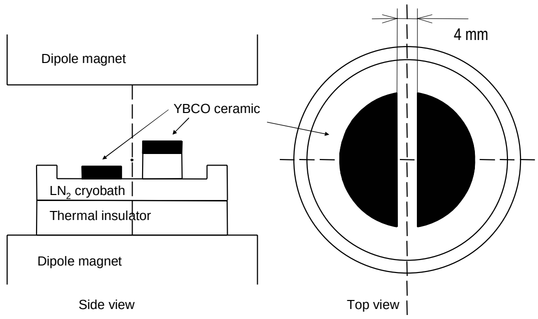

Fig. 6 Experimental setup.

Test piece was cut into two 'D shapes' for the transverse magnetic field measurement. The test pieces were cooled down to 77 K in a LN_2 cryobath. After cooled down below the critical temperature, they were moved into the gap of the dipole magnet. Longitudinal magnetic field of the strength in the range of 2 mT to 15 mT was applied. The magnetic field strength was measured using a Hall probe. The measured strength was about 0.5 mT, and did not depend on the amplitude of the longitudinal magnetic field.

DISCUSSION

Transverse magnetic field was successfully generated with YBCO test pieces, but the magnitude was very small. Let us discuss on the small transverse magnetic field strength. Although the upper critical field strength for the YBCO is high, the lower critical field is about 1 mT. Thus, the magnetic vortex lines penetrate into the superconductors. As a result the enough transverse magnetic field was not produced.

To overcome this problem, strong pinning center should be introduced. Then the penetration of the vortex lines would be suppressed. Doping of Praseodymd[2] is planned to introduce pinning center and increase critical current density.

Although, zero-field cooling is introduced in this work, filed cooling is also considerable to produce transverse magnetic field. If the each superconducting pieces with strong pinning center are cooled in the strong solenoid field, each pieces work as strong permanent magnet of several T after the solenoid field is turned off. Such strong permanent magnet would increase the performance of hybrid staggered undulator [3]. Although the peak field depends on the trapped magnetic field by the superconducting pieces, recently typical trapped field is greater than 2T [4], thus the peak field of greater than 1T is expected.

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