Broad Band Energy Science Research Section

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1. Introduction

We are engaged in research aimed at new applications of energy over a wide range of spatiotemporal scales. For magnetic field energy and plasma energy, we are working on establishing powerful and precise magnetic field control methods, pioneering new local high field and strong gradient applications, optimizing fusion plasma confinement by magnetic fields, and clarifying plasma transport phenomena.

2. Generation of strong periodic magnetic field

Synchrotron radiation is produced when charged particles are accelerated. If the acceleration is periodically applied by a device that generates a periodic magnetic field, so called an undulator, intense synchrotron radiation can be obtained via interference. Therefore, generation of strong and precise periodic magnetic field is quite attractive to develop high performance future synchrotron light sources. The resonant wavelength of the emitted radiation from planer undulator λ_R can be expressed using period length of the undulator λ_U, energy of the electron beam E, and the maximum transverse magnetic field strength of the undulator B_0 as following equations (1) and (2).

$$\lambda_R[\text{Å}] = \frac{\lambda_U}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$

$$\approx 13.056\frac{\lambda_U[\text{cm}]}{(E\,[\text{GeV}])^2}\left(1+\frac{K^2}{2}\right) \quad (1),$$

$$K = \frac{e \cdot B_0 \cdot \lambda_U}{2\pi \cdot m_0 c} \approx 93.36 B_0[T] \cdot \lambda_U[m] \qquad (2).$$

Here, γ is the Lorentz factor, K is the undulator parameter which determines property of radiation, e is the charge of the electron, m_0 is the mass of electron, and c is the speed of light. The unit of wavelength is Å, undulator period length is cm, electron energy is GeV, and magnetic field is Tesla respectively. According to Eq. (1), use of high energy electron beam is essential to generate short wavelength synchrotron lights. Thus, high brightness hard X-ray higher than 10 keV, which play an important role in material science, has been provided mainly at 6-8 GeV-class large synchrotron radiation facilities such as SPring-8 or high-energy linac facilities such as SACLA. In order to increase usability of the hard X-ray, new innovative technology for generation of hard X-rays in a compact and energy-saving 3 GeV-class accelerator facilities is desired. Therefore, we focused on bulk superconductors, which can handle ultra-high currents, and have been working on an innovative undulator that enable to generate hard X-ray even at the 3 GeV-class accelerator facility.

The new undulator consists of stacked bulk high critical temperature superconductor array and a 6 T superconducting solenoid magnet. In this year, we have developed a hybrid array structure consisting bulk GdBaCuO superconductor and vanadium permendur. Photograph of the new undulator prototype and the hybrid array is shown in fig. 1. Magnetic field performances were widely surveyed for different period length, structure, and operating temperature (fig. 2)

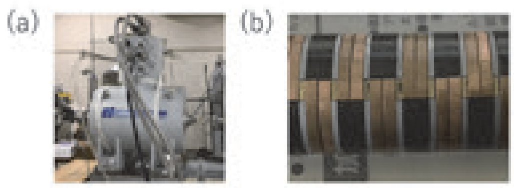

Fig. 1 (a) Photograph of the new unduloator prototype and (b) the new hybrid stacked array.

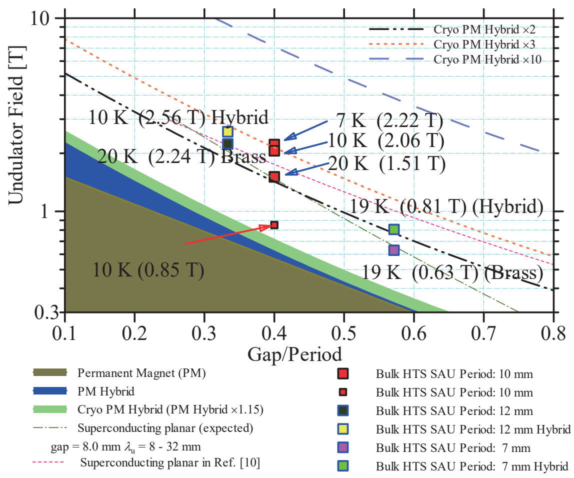

Fig. 2 Performance comparison

Compared to conventional permanent magnet undulators, the performance of this type of undulator is about twice as high at 20 K and about three times as high at 10 K over a wide range of gap/period ratios.

3. Introduction

The transport barrier formation in magnetic confinement plasmas has been the central topic for achieving fusion reactor. Especially, the internal transport barrier (ITB) is essential for steady-state operation in tokamaks, because the ITB drives plasma current to keep the plasma confinement stable. Conventionally, the ITB is formed due to local turbulence suppressions, however, several experiments suggest the global dynamics of ITBs that extend beyond the range of turbulence reduction regions. Based on these backgrounds, we have investigated the global transport effect on the ITB formation observed in JT-60U tokamak plasmas [1].

4. Impact of avalanching transport on the internal transport barrier (ITB) formation

We have investigated the avalanche type of transport, which is a domino-like event that propagates sequentially to neighbors via local critical excitations. Since avalanches can propagate with a long-radial distance, the study of avalanches could provide new insights into the formation mechanism of the ITB.

In this experiment, the power of the neutral beam (NB) injection was scanned to investigate the ITB transition in JT-60U plasmas, with NB powers of 8, 10, 11 and 12 MW. We have detected the avalanche events from density fluctuations measured by reflectometer. As shown in Fig. 1, density fluctuation level is increased when the NB power reaches 10 MW. In addition, the density fluctuation intermittently increases in time, showing a bursty feature. The bursty increases of density fluctuations, called as bursty fluctuation (BF), are synchronized to the large avalanche events in electron temperature fluctuations measured by electron cyclotron emission (ECE) diagnostics. At the avalanche events, the electron temperature fluctuation indicates void (δ Te < 0) and bump (δ Te > 0), propagating in opposite direction to relax the electron temperature gradient.

When q_{min} (minimum value of the safety factor) crosses the rational surfaces, a transient increase of temperature is phenomenologically observed in tokamaks. Similar to the previous studies, electron temperature is increased when q_{min} reaches 5 (Fig. 3). The T_e increases were transient in the 8, 10, and 11 MW discharges, whereas the T_e increase was continuous in the 12 MW discharge and finally reached the stationary ITB. The BFs continuously and partially appeared in the 10 and 11 MW discharges, whereas they were completely decreased in the 12 MW discharge. Especially in the 11 MW discharge, the short-time decay of the electron temperature is synchronized to the BFs. From these results, we found that the formation of ITB is disturbed by the occurrence of avalanches.

Acknowledgement

These researches were partly supported by grants from JSPS KAKENHI (JP22H03870).

[1] F. Kin et al., *Sci. Rep.*, **13**, 19748 (2023).

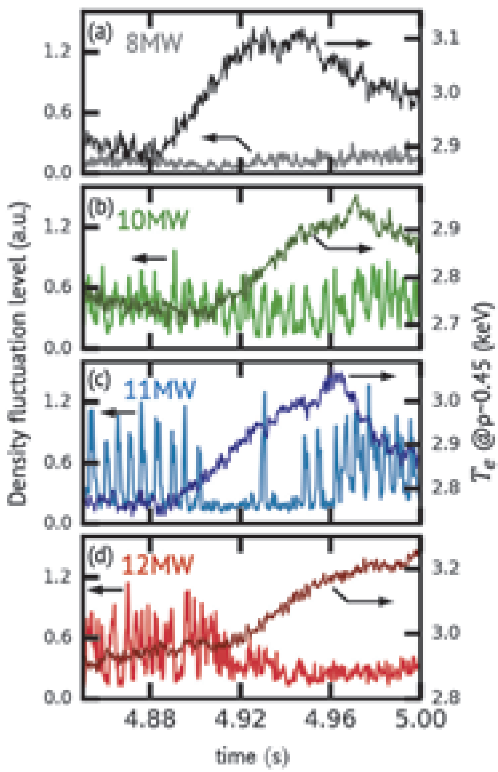

Fig. 3 Temporal evolution of BFs and electron temperature for NB-power of (a) 8MW, (b) 10MW, (c) 11MW and (d) 12MW.

Financial Support

Grant-in-Aid for Scientific Research
紀井俊輝, 基盤研究(B), バルク超伝導体アンジュレータへの電子ビーム入射

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