Development of a Light Source Based on a 100-mm-Long Monolithic Undulator Magnet with a Very Short 4-mm Period Length

We are exploring a novel method to fabricate undulator magnets having a period length of a few millimeters. Magnet plates 100 mm long with a 4-mm period length have been successfully fabricated. They produce an undulator field of approximately 3.2 kG at a gap of 1.5 mm. A prototype in-vacuum undulator based on this technology has been constructed. A test experiment for light generation using a real electron beam has been carried out with the S-band linac operating at 33.5 MeV. The first observation and characterization of blue light was accomplished successfully.

The period length of an undulator, λ_u, is one of the important parameters which control the spectral properties of synchrotron light sources. If an undulator with a very short period length was available, synchrotron radiation with shorter wavelengths could be obtained at a given energy of the electron beam, thus expanding the research field in synchrotron radiation science. Accordingly, we have been developing a novel method to construct undulators with very short period lengths [1-4]. These undulators may reduce the size and construction cost of light sources and resolve financial obstacles to the development of many future projects involving new light sources.

We have been trying to develop a completely new method to fabricate undulator magnets with a period length of 4 mm as the current target. This period length was selected since 12-keV radiation can be obtained with the first harmonic of this undulator in the 2.5-GeV accelerator which has the same electron beam energy as the PF. Here, a multi-pole magnetizing method is used to magnetize the thin plate of the magnets [1-5].

After several trials, we finally devised the present method shown in Fig. 1 [6]. The plate monolithic magnet made of Nd-Fe-B material is embedded between a pair of magnetizing heads of electromagnets. It is longitudinally driven by a linear motor step-wise and magnetized with a periodic spacing by the fixed head as shown in Fig. 1(a) [6]. The step width of the moving plate is set to a half of the period length of the magnetic field. At each step of the plate movement the pulse current applied to the head is reversed in direction to form the undulator field. After the magnetization, a pair of these plates is combined with faces opposing each other, and the undulator magnetic field is produced in the short gap between the plates as shown in Fig. 1(b) [6].

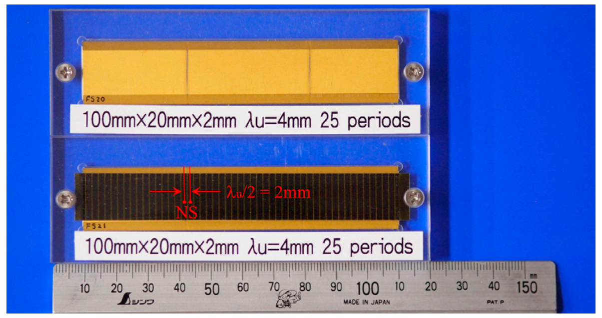

Figure 2: Plate magnets after magnetization 100 mm long with 4-mm period length, which are made of Nd-Fe-B material and coated with TiN. The lower plate is covered by a magnetic viewer sheet, and the magnetic field pattern is seen through it. Reproduced from Ref. [6] with permission of the International Union of Crystallography.

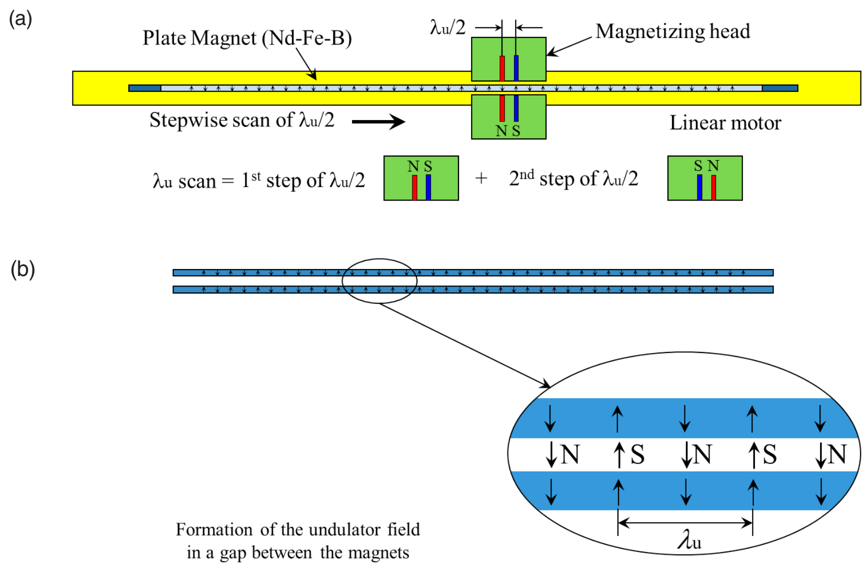

Figure 1: (a) Schematic illustration of magnetization method of the plate monolithic magnet. **(b)** Formation of an undulator field with plate monolithic magnets. Reproduced from Ref. [6] with permission of the International Union of Crystallography.

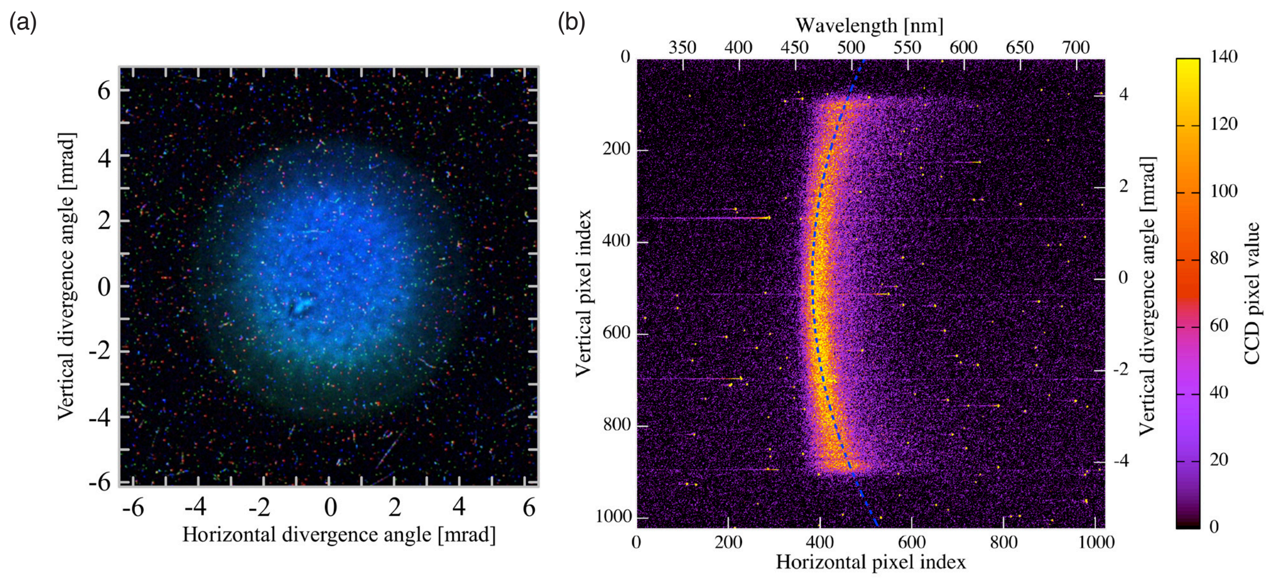

Figure 3: (a) The 2-dimensional profile of the undulator radiation observed by the color CCD camera. **(b)** A single-shot 2-dimensional spectroscopic image of undulator radiation when the undulator gap was 1.5 mm. Horizontal and vertical pixel positions correspond to the wavelength and vertical divergence angle of the radiation, respectively. The bright line forming an arc represents the undulator radiation. The dotted curve shows angle dependence of radiation wavelength. CCD pixel values are represented by the color bar. Reproduced from Ref. [6] with permission of the International Union of Crystallography.

The magnetized plates 100 mm long with 4-mm period length are shown in Fig. 2 [6]. They are made of NEOMAX-37SH (Hitachi Metals Co. Ltd.) and coated with TiN for vacuum sealing. The magnetic field pattern is seen through a magnetic viewer sheet for one of the plate magnets in Fig. 2 [6]. Magnetic field characterization based on the measured field shows that the quality of the undulator field of these plate magnets is satisfactory.

In order to install these plate magnets, we designed and constructed a prototype in-vacuum undulator [5], in which the plate magnets 100 mm long are installed in a vacuum chamber.

A light source test experiment was performed with the test Accelerator as a Coherent Terahertz Source (t-ACTS) at the Research Center for Electron Photon Science (ELPH), Tohoku University [7] by observing the synchrotron radiation from the prototype undulator. The parameters of the t-ACTS which was operated at 2 Hz repetition in the test were as follows: electron beam energy and its spread 33.5 MeV and 0.44%, beam current 10 mA, and normalized emittances in the horizontal and vertical directions 5×10^{-6} m and 4.4×10^{-6} m, respectively.

The spatial profile of the synchrotron radiation from the 4-mm-period undulator was observed by a color CCD camera as shown in Fig. 3(a) [6]. The blue color of the radiation is consistent with the deflection parameter, K, of 0.12 at the gap of 1.5 mm (B_0 = 3.2 kG). Spectroscopic measurements were made by using an imaging spectrometer equipped with the EM-CCD camera with an electron multiplying function for high sensitivity measurements. Spectroscopic data was shown as the number of photons acquired on each pixel, with the horizontal position of the CCD plane corresponding to the wavelength, λ, of the undulator radiation, and the vertical position corresponding to the vertical divergence angle, θ, from the light axis. An example of the two-dimensional image data is shown in Fig. 3(b) [6] for the undulator gap of 1.5 mm. The dotted line along the bright arc on the image represents the nature of the undulator radiation given by the relation $\lambda = \lambda_u(1 + K^2/2 + \gamma^2\theta^2)/2\gamma^2$ with the electron beam energy, γ.

Our next target is to produce a longer magnetic field with larger number of periods. We have started work on obtaining a long field by connecting several plate magnets. For this purpose, we have developed a new connection method and succeeded in fabricating a longer undulator with 500-mm magnet length (125 periods) [5]. We found that this 500-mm undulator field was satisfactory and useful.

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