Conceptual Design of the Hybrid Ring: Towards Simultaneous Use of Two Synchrotron Radiation Beams

The ILC type long-pulsed superconducting linear accelerator (LINAC) can efficiently generate high-current electron beams with ultra-high performance. The Hybrid Ring adopts such LINACs as an injector to the high-performance storage ring light source. With this configuration, users can use both synchrotron radiation from the conventional storage (SR) electron bunches and the single pass (SP) electron bunches with ultra-low emittance and/or ultra-short pulse directly from the injector. In addition to a single beam, either from SP or SR, two simultaneous beams are potentially available, which allows developments of epochal user experiments that can contribute to a wide range of scientific and technological fields.

The conceptual design of an epochal synchrotron radiation facility, called the Hybrid Ring, is proposed at the Photon Factory (PF). The PF is the first dedicated synchrotron radiation facility where high-energy synchrotron radiation X-rays were first available in Japan in 1982. To promote conventional methods developed at the PF, to achieve the cutting-edge beam performance, and to enable a new type of user experiment by simultaneously using two synchrotron radiation beams, a new idea, the Hybrid Ring, is introduced [1].

The Hybrid Ring comprises a multi-purpose and user-friendly storage ring with the most advanced and flexible long-pulsed superconducting (SC) linear accelerator (LINAC) used as an injector (**Fig. 1**). In the Hybrid Ring, the conventional synchrotron radiation beam from the storage (SR) beam is available at all beamlines. At the isochronous part of the ring (approximately 2/3rd of the entire circumference), users can also use synchrotron radiation generated by a single-pass (SP) beam directly from the injector. The SP beam exhibits the most advanced parameters because the injector LINAC can generate ultra-low emittance and/or ultra-short pulse beams with flexibility in the beam size, pulse width, and beam repetition rate. These parameters are typically fixed in conventional storage rings. In addition to the single-beam experiment, users can simultaneously use two synchrotron radiation photons from SR and SP beams.

A long-pulsed SC LINAC of International Linear Collider (ILC)-type is employed as an injector to realize the conventional top-up injection for SR beams and to generate SP beams. It has been developed at KEK in collaboration with overseas research institutes for the ILC project. The ILC-type LINAC can efficiently generate a high-current beam due to the multi-bunch acceleration in long macro-pulses. The pulsed operation can minimize the heat load and required capacity of the cryogenic system. The output current can drastically be increased by more than 1,000 times compared to that generated by a conventional normal conducting LINAC with a slight increase in the construction and operation costs. For example, in the free-electron laser facilities overseas using the long-pulsed SC LINAC as free electron laser in Hamburg (FLASH) and European X-ray free-electron laser facility (European XFEL), the beam parameters are the RMS emittance of approximately 0.4 nm·rad (at 3 GeV), RMS pulse width of 65.5 fs, and average current of approximately 27 μA [2]. For the example of the Hybrid Ring presented in article [1], the tentative beam energy is 3 GeV and the SR beam current is 500 mA. The target parameters for the SP beam are an RMS emittance of 0.1 nm·rad, RMS pulse width of 50 fs, bunch charge of 1 nC, and average current of 0.1 mA. At the first stage, these parameters may be separately available for user experiments with dedicated modes.

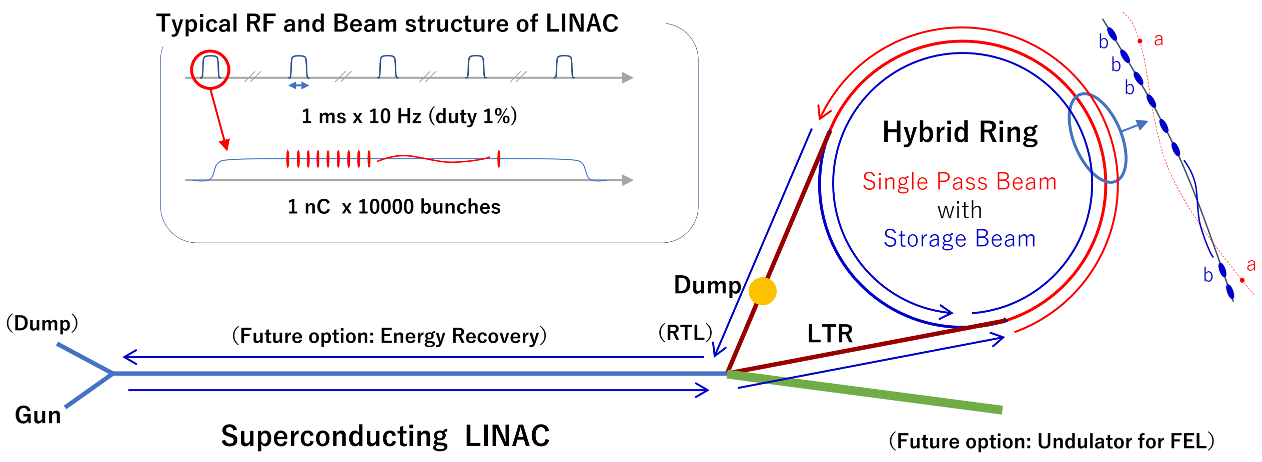

Figure 1: Conceptual diagram of the Hybrid Ring. The Hybrid Ring is a combination of a partially isochronized low-emittance storage ring with a long-pulse superconducting linear accelerator. Users can use not only conventional storage beam (shown with signature "b") but also single pass beam from LINAC (shown with signature "a") selectively and/or simultaneously.

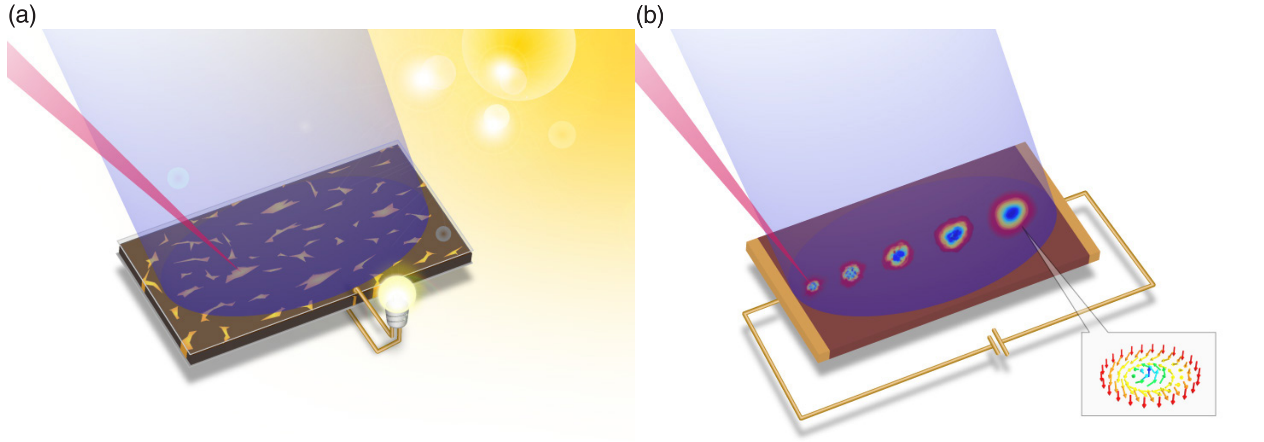

Figure 2: Examples of two-beam applications. In both cases, the relative position of the SP and SR beams is adjustable. **(a)** Two X-ray probes for a solar cell. **(b)** X-ray pump & X-ray probe for a spintronics device.

To transport the electron beam from the injector to the beamline part of the storage ring while maintaining the beam parameters, lattice and optics optimizations are required. The solution is to partially isochronize low-emittance optics with a small dispersion and large curvature radius in shortly divided bending magnets like the recent multi-bent achromat type lattice. By adopting such lattice and optics, the beam emittance and bunch length can be maintained for high quality.

The applications of two simultaneous synchrotron radiation beam experiments in the Hybrid Ring are, for example, research on artificial photosynthesis, solar cells, and photocatalysts [3-5]. These subjects may be essential for the realization of a sustainable society. In the experiment, the slow changes occurring in the entire sample can be measured by the conventional synchrotron radiation from the SR beam, while the rapid local changes at the interfaces and phase boundaries are simultaneously measured by the ultra-high-performance synchrotron radiation from the SP beam [**Fig. 2(a)**]. The mechanism of the photochemical reactions can be solved. The SR and SP beams can also be used as pump-and-probe experiments. For example, magnetic skyrmions [6-8], which are promising nano-scale spin texture for the next-generation magnetic data storage, are generated by short-pulsed synchrotron radiation from SP beam [9] and measured by conventional synchrotron radiation from SR beam [**Fig. 2(b)**]. The fundamental mechanism of the generation and control of magnetic skyrmions can be analyzed.

To realise the Hybrid Ring, the research and development (R&D) for injector will be made with Innovation Center for Applied Superconducting Accelerators (iCASA) using Compact Energy Recovery LINAC (cERL) and Superconducting RF Test Facility (STF). To prepare for the two-beam user experiment, the planned R&D beamline at PF will be used in collaboration with HiSOR facility (Hiroshima Univ.) and UVSOR facility (Institute for Molecular Science). Beam diagnostics and handling studies for SP beams will be conducted in PF and PF-AR using a normal injection beam from KEK injector LINAC.

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