6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

High resolution imaging and CT using a table-top ultrafast synchrotron radiation source

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Radio-frequency (RF) based accelerators are an essential tool in modern scientific research, medicine and health care, industrial non-destructive detection, food irradiation preservation and large-scale security inspection systems, promoting the progress of science and the development of society. However, due to the RF breakdown triggered by field emission in high voltage, the acceleration gradient of RF based accelerators is general less than 100 MV/m. The limited acceleration gradient makes the scale and cost of these facilities relatively high, especially in the application of high energy beams, such as synchrotron light sources and free electron lasers. Laser wakefield accelerators (LWFA), first proposed by Tajima and Dawson in 1979, utilize the plasma wakefield excited by the interaction between ultra-intense ultra-short laser pulses and underdense plasmas to accelerate electrons with an acceleration gradient of >100GV/m, promising to reduce the required acceleration distance by 3 orders of magnitude compared to the RF based accelerators. Benefitting from μm-scale dimensions of the plasma wakefield, the electron beams and x-ray sources driven by LWFA are naturally featured few-femtosecond (fs) duration, μm-level transverse size and high brightness. With the intensive development of LWFA in the past two decades, key principles and advanced concepts to generate electron beams with GeVs energy, low emittance and kiloampere peak current have been verified, and phase-contrast imaging, computed tomography and ultrafast x-ray absorption spectroscopy performed with betatron sources and all-optical inverse Compton scattering sources have been demonstrated. These results show that LWFA is capable of becoming a competitive candidate for the next generation compact light sources and electron-positron colliders.

LWFA is sensitive to temperature, humidity and cleanliness. Temperature fluctuation causes mechanical deformation of optomechanical components, resulting in the pointing jitter and quality deterioration of laser beams. Humidity fluctuation and poor cleanliness cause optical surface contamination, even damage the optical mirrors, lenses and crystals. To date, general LWFA systems are almost installed in fixed laboratories or facilities with relatively large scales to meet the operation requirements of a clean environment with constant temperature and humidity. It is still a major challenge for LWFA to operate reliably, steadily and flexibly in a complicated environment for different application scenarios.

Here, we have developed a real table-top LWFA based ultrafast synchrotron radiation source having a size of 1.5m×3m. The apparatus, consisting of an industry level compact 40TW Ti:Sapphire laser (also developed by ourselves) and a compact vacuum system capable of 10Hz repetition frequency, has been proved to have a capacity of continuous and stable operation for a few days. Utilizing the table-top synchrotron radiation source, high resolution images and computed tomography of biological and industrial specimens with a 10μm-level resolution are obtained. Our work paves a way for the application and industrialization of high resolution imaging based on the table-top ultrafast synchrotron radiation source.