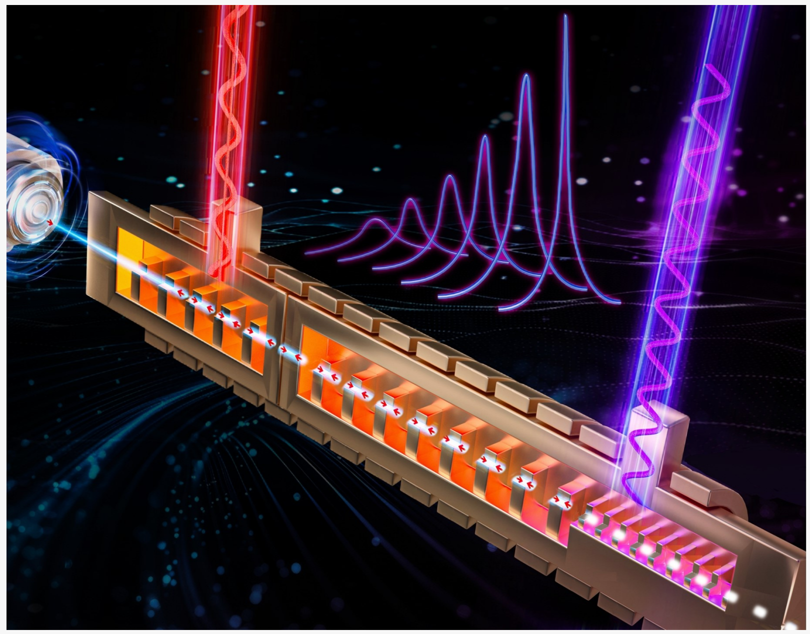
Pump-induced stimulated superradiant Smith-Purcell radiation with ultra-narrow linewidth

FAYETTEVILLE, GA, UNITED STATES, April 18, 2025 /EINPresswire.com/ -- Free electron lasers have unique advantages of high power, wide frequency tunablility and et al, however, they face challenge in narrowing the spectral linewidth. Scientists in China proposed and realized the pump-induced stimulated superradiant Smith-Purcell radiation (PIS-SPR) and achieved an ultra-narrow spectral linewidth of 0.3 kHz at ~0.3 THz in a compact device. The mechanism and technique provides a way to further narrow the spectral linewidth of free electron radiation and broaden its applications.



Pump-induced stimulated superradiant Smith-Purcell radiation (PIS-SPR) and compact device.

Superradiant Smith-Purcell radiation (S-SPR) is a kind of free electron radiation with a train of free electron bunches passing over a periodic grating. In theory, ultra-narrow spectral linewidth of S-SPR could be realized, which would be greatly beneficial to various applications such as imaging, sensing, communication, and et al. However, in the free electron accelerators, customized setups and orotrons, the instability of electron kinetic energy, coulomb effect and the finite number of electron bunches worsened the radiation linewidth, and the large size of equipment limits the application scenarios.

In a new paper published in eLight, a team of scientists, led by Professor Fang Liu and Yidong Huang from Department of Electronic Engineering, Tsinghua University China, and co-workers have developed the first compact S-SPR device with ultra-narrow and continuously tunable spectral linewidth. They proposed the new effect of pump-induced stimulated S-SPR (PIS-SPR) and observed successfully the PIS-SPR at the frequency of ~0.3 THz with radiation linewidth continuously tuned from 900 kHz to 0.3 kHz. The device can even be easily held by one hand with the size of 22 cm × 7 cm × 6.5 cm and the weight of only 1.68 kg.

Such compact device with PIS-SPR effect includes three sections: the electron pre-bunching, electron-compression and harmonic-emission section. The scientists summarize the operational principle of PIS-SPR: “The low-frequency and low-power THz pump wave excites the localized electromagnetic mode on the grating which pre-bunches the electron beam. Subsequently, these pre-bunched electrons emit S-SPR at the same frequency as the pump wave. With an F-P cavity, the localized electromagnetic mode and the electron bunching are enhanced alternatively and continuously, which leads to the stimulated S-SPR (namely PIS-SPR), as well as well-bunched periodic electrons. Finally, utilizing the small period grating, the ideal electron bunches could generate high harmonic S-SPR.”

With PIS-SPR effect, the three factors worsening the radiation linewidth, namely instability of electron kinetic energy, coulomb effect and the finite number of electron bunches, had been overcome. They tuned the emission spectrum linewidth from 900 kHz to 0.3 kHz, by varying the number of electron bunches from ~105 to ~109. Compared with previous reported S-SPR generated by electron accelerators or other equipment, the linewidth could be shrunk by about two~six orders of magnitude, and the spectral linewidth could be tuned continuously in range of 0.3 kHz~900 kHz.

These scientists also found that the device can be operated in the model of backward waveguide mode (BWM) with no pump wave injected. The electron bunches and 3rd harmonic S-SPR was also observed, but the linewidth is wider than MHz. “The mode evolution of the device from BWM-induced S-SPR to PIS-SPR is observed experimentally by gradually increasing the power of pump wave from 0 mW to 60 mW. The BWM is gradually suppressed with increased pump power, and the PIS-SPR dominates the electron bunching process.” They explained.

“This work provides the possibilities of not only realizing compact, narrow linewidth radiation sources in different frequency region which would promote the applications of S-SPR in different fields, but also generating frequency-locked/-tunable free electron bunches for interaction with different materials and micro-/nano-structures. And the proposed stimulated effect to enhance the light field might also be considered for on-chip electron acceleration to achieve a higher electron acceleration gradient.” the scientists forecast.

References
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