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Nanophotonics in the relativistic realm

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Nanophotonics is based on the interaction of light with nanometer sized objects [1]. It provides formerly inaccessible sub-wavelength focusing and electro-magnetic field enhancement. Nowadays, it is broad research field with many proof-of-principle studies, especially acceleration of electrons [2] and practical applications [3]. Nanophotonics has been investigated with laser intensities up to about 1014 W/cm2 [1 and references therein], but at higher intensities very few experiments were performed [4] with only long laser pulses. However, many promising applications could be realized, among others the generation of attosecond relativistic electron bunches, when using much higher intensities exceeding 1018 W/cm2, the so-called relativistic limit. The emitted electrons have kinetic energies beyond their rest mass, i.e. 0.5 MeV. Therefore, the interaction is naturally in the sub-cycle regime [5], i.e. the electrons do not quiver in the laser field, but run parallel to it having almost the speed of light and interact with only a sub-cycle part of it.
Here we report on the first nanophotonics experiment in the relativistic realm driven by a sub-5-fs laser. We used the Light Wave Synthesizer 20 [6], an 18 TW sub-5-fs optical parametric synthesizer, focused to intensities approaching 1020 W/cm2. We inserted tungsten needle targets with 100 nm diameter into the laser beam. Due to the very good temporal contrast and the short pulse duration of the laser clean interaction conditions were provided. Relativistic electrons were generated and detected in specific directions. The angular distribution, spectrum, and charge were measured. The dependence of the electron angular distribution and charge was determined on various parameters. The spectrum was carefully measured and showed electrons up to 9-10 MeV kinetic energy. Furthermore, the influence of the laser waveform (carrier-envelope phase) on the electron beam properties was also investigated.
The experimental observations are supported by detailed particle-in-cell simulations. Very good agreement is obtained between the experiments and the numerical investigations. These simulations indicate that the interaction is well separated into two consecutive parts, including the nanophotonics and the vacuum laser acceleration steps. Our observations are hinting to accelerating electric field gradients as high as a few-TV/m, significantly stronger than all other techniques. Furthermore, they support the extension of nanophotonics into the relativistic realm and form the basis of a long-desired electron acceleration mechanism directly by lasers in vacuum.

References

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