Physicists control the flow of electron pulses through a nanostructure channel

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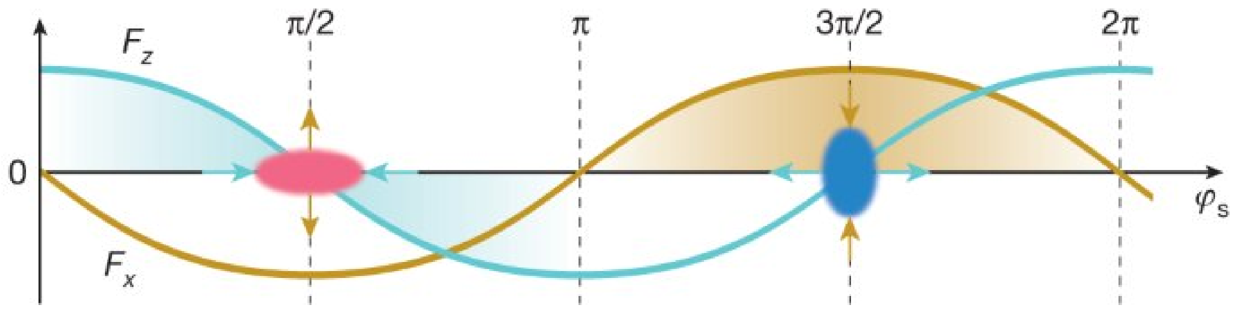

Fig. 1: Forces acting as a function of the synchronous phase φs. Credit: DOI: 10.1038/s41586-021-03812-9

Particle accelerators are essential tools in research areas such as biology, materials science and particle physics. Researchers are always looking for more powerful ways of accelerating particles to improve existing equipment and increase capacities for experiments. One such powerful technology is dielectric laser acceleration (DLA). In this approach, particles are accelerated in the optical near-field which is created when ultra-short laser pulses are focused on a nanophotonic structure. Using this method, researchers from the Chair of Laser Physics at Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) have succeeded in guiding electrons through a vacuum channel, an essential component of particle accelerators. The basic design of the photonic nanostructure channel was developed by cooperation partner TU Darmstadt. They have now published their joint findings in the journal *Nature*.

Staying focused

As charged particles tend to move further away from each other as they spread, all accelerator technologies face the challenge of keeping the particles within the required spatial and time boundaries. As a result, particle accelerators can be up to ten kilometers long, and entail years of preparation and construction before they are ready for use, not to mention the major investments involved. Dielectric laser acceleration, or DLA, uses ultra-fast laser technology and advances in semi-conductor production to potentially minimize these accelerators to merely a few millimeters or centimeters in size.

A promising approach: Experiments have already demonstrated that DLA exceeds currently used technologies by at least 35 times. This means that the length of a potential accelerator could be reduced by the same factor. Until now, however, it was unclear whether these figures could be scaled up for longer and longer structures.

A team of physicists led by Prof. Dr. Peter Hommelhoff from the Chair of Laser Physics at FAU has taken a major step forward towards adapting DLA for use in fully-functional accelerators. Their work is the first to set out a scheme which can be used to guide electron pulses over long distances.

Technology is key

The scheme, known as 'alternating phase focusing' (APF) is a method taken from the early days of accelerator theory. A fundamental law of physics means that focusing charged particles in all three dimensions at once—width, height and depth—is impossible. However, this can be avoided by alternately focusing the electrons in different dimensions.

First of all, electrons are focused using a modulated laser beam, then they 'drift' through another short passage where no forces act on them, before they are finally accelerated, which allows them to be guided forward.

In their experiment, the scientists from FAU and TU Darmstadt incorporated a colonnade of oval pillars with short gaps at regular intervals, resulting in repeating macro cells. Each macro cell either has a focusing or defocusing effect on the particles, depending on the delay between the incident laser, the electron, and the gap which creates the drifting section. This setup allows precise electron phase space control at the optical or femto-second ultra-timescale (a femto-second corresponds to a millionth of a billionth of a second). In the experiment, shining a laser on the structure shows an increase in the beam current through the structure. If a laser is not used, the electrons are not guided and gradually crash into the walls of the channel. "It's very exciting," says FAU physicist Johannes Illmer, co-author of the publication. "By way of comparison, the large Hadron collider at CERN uses 23 of these cells in a 2,450 meter long curve. Our nanostructure uses five similar-acting cells in just 80 micrometers."

When can we expect to see the first DLA accelerator?

"The results are extremely significant, but for us it is really just an interim step," explains Dr. Roy Shiloh, "and our final goal is clear: We want to create a fully-functional accelerator—on a microchip."

Work in this area is being driven by the international 'accelerator on a chip' (ACHIP) collaboration, of which the authors are members. The collaboration has already proven that, in theory, APF can be adjusted to achieve acceleration of electron beams. Complex, three-dimensional APF setups could therefore form the basis for the particle accelerator technology of the future. "We have to capture the electrons in all three dimensions if we are to be able to accelerate them over longer distances without any losses," explains Dr. Uwe Niedermayer from TU Darmstadt, and co-author of the publication.

More information: R. Shiloh et al, Electron phase-space control in photonic chip-based particle acceleration, *Nature* (2021). DOI: 10.1038/s41586-021-03812-9

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