Accelerators moving on

Particle accelerators are one of the most remarkable pieces of apparatus to come out of twentieth century science. *Nature Photonics* spoke to Nasr Hafz who, with the help of colleagues, is working towards more compact and thus more affordable accelerators based on lasers.

Tell us about your research.
Our work at the Advanced Photonics Research Institute in Korea involves accelerating electrons using laser beams. We inject laser light into a plasma (an ionized gas) and excite the plasma in such a way that very strong electric fields are created over very short distances — on the order of a few millimetres. Charged particles — in our case electrons — can then be accelerated by this electric field. It turns out that we can generate the same field strength over a distance of less than 1 cm that conventional radiofrequency cavities can only create over several hundreds of metres. That is the advantage of the laser–plasma approach.

How exactly does the electric field develop?
The plasma is full of electrons and ions. As the laser travels through the plasma it causes charge separation, leaving behind it a so-called wakefield — a longitudinal plasma oscillation. Some of the electrons in the plasma get trapped in the wakefield and travel along with this wave for a certain distance — typically a few millimetres — before they dephase, at which point they no longer acquire any more energy from the plasma oscillation. We extract the electrons at that point. To make this work, we have to design the length of the plasma and the plasma density very carefully to make sure the electrons do not dephase too quickly.

Tell us more about the laser system you use.
Our experimental room is about 5 m wide and 15 m long. Half of that is taken up by the laser system. We use extremely intense laser beams with powers of up to 50 TW, and pulses that are 35 fs long. The ion motion within the plasma is at a rate of the order of picoseconds, so the pulse duration has to be shorter than that to make sure the beam is stable as it travels through the plasma and does not get disturbed. The spot size of the focused laser beam is about 25 μm full-width at half-maximum. Previous experiments have used 5- or 10-μm spot sizes, but we have found that a larger focal spot produces a more energetic, more stable beam of electrons.


APRI

Accelerator players: Nasr Hafz (left) and Jongmin Lee (right).

We focus the laser in the plasma using various optics, to ensure that the light beam travels as far as possible before it diffracts. There are several techniques to overcome the diffraction. If the laser beam is very intense, as in our case, an effect known as self-guiding can occur, in which the laser essentially focuses itself and can travel over larger distances.

What about the plasma?
The interaction chamber is housed in a shielded room and is less than 2 m long. We use several-millimetre-long jets of helium gas as the source of the plasma. This is in contrast with other accelerators that rely on capillaries instead of gas jets, which are much harder to control and tend to be less compact. Our gas jets are high-quality supersonic jets with a Mach number of five, and they are emitted vertically to interact with the laser beam. It is important that the gas jet has a sharp profile so that it doesn't defocus the laser prior to interaction.

The experiment sounds simple in theory, but in practice it isn't. One run of the experiment takes 1–2 months to complete. The laser–plasma interaction has to be very finely tuned. For example, it takes many trials just to focus the laser correctly onto the gas jet.

So what kind of acceleration do you achieve?
We have managed to create electron beams with energies over 1 GeV that are, crucially, very stable and reproducible (the energy of the accelerated electrons fluctuates less than 5%). Only two groups have successfully managed to produce gigaelectronvolt-scale electron beams — us and researchers at Lawrence Berkeley National Lab, who also have access to a 50-TW laser beam. The Berkeley group used a similar laser system but the plasma was about ten times longer. The stability of the acceleration process is critical if laser-based accelerators are to become a practical reality, and that requires a very stable laser system.

Where next?
Many labs around the world, including ours, are building petawatt-class lasers. With petawatt light (and larger spot sizes) we expect to be able to reach far higher electron beam energies — of the order of tens of gigaelectronvolts. Petawatt lasers also allow us to study the interaction of laser light with certain solids to generate protons and X-rays. In the next year or so our aim is to use 100-TW beams of light. We have already produced electron beams with 2–3 GeV of energy, but the number of electrons at these energies was small.

In the longer term, Jongmin Lee (the project leader) is planning to move into free-electron-laser (FEL) work, which is a very exciting area of research. Free-electron lasers use electrons instead of gases or solids as the lasing medium and could lead to high-intensity ultrashort sources of X-rays. Conventional FELs are very expensive with most of the cost going towards the construction of large linear accelerators. Our hope is to eventually create an X-ray FEL using our compact electron accelerators at a much cheaper price.

Interview by Amber Jenkins.

Hafz and his colleagues have an Article on laser–plasma accelerators on page 571 of this issue.