Accelerator on a Chip: Recent Progress (700MeV/m)

A Path to TeV Energy Scale Physics and Table Top Coherent X-rays

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Abstract

Dielectric Laser Accelerators, accelerators on a chip, offer a new approach to the next generation of accelerators. The recently demonstrated gradient of 700MeV/m is a first step toward an accelerator on-a-chip fabricated using modern lithographic methods. Accelerators on a chip enable attosecond physics from the XUV to X-ray region and open the possibility of TeV energy scale physics in the future

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Particle accelerators

Small really is beautiful

Fundamental physics seems to have an insatiable appetite for bigger, more expensive machines. There may, though, be a way to shrink them radically

BIG science tends to get bigger with time. The first modern particle accelerator, Ernest Lawrence's cyclotron, was 10cm across and thus fitted comfortably on a benchtop. It cost (admittedly at 1932 prices) $25. Its latest successor, the Large Hadron Collider (LHC), has a diameter of 8.6km (5.3 miles) and does not even fit in one country: it straddles the border between France and Switzerland, near Geneva. It cost $5 billion. Clearly, this is a trend that cannot continue. And two groups of physicists, one American and one German, think they know how to stop it. Their suggestion, which (if it works) will benefit not only physics but also cancer treatment, is to cease making accelerators out of metal and start making them out of glass.

A modern particle accelerator consists of a series of specially shaped cavities surrounded by a metal (usually copper) through which an alternating voltage is passed. When this voltage is positive, the cavity attracts negatively charged particles (normally electrons), and draws them in; when it is negative, it repels and expels them. If the particles to be accelerated are positive (such as protons) the principle is the same but the voltages are the other way around.

The trick is to switch the voltage at precisely the moment a particle passes through a cavity, to give that particle a kick. Repeat the process with enough cavities and a high enough voltage, and you can get it zipping along at close to the speed of light. Such accelerators can be built in a straight line, and for some experiments this is the best arrangement. But the cavities may also, as is the case for the LHC, be arranged in a circle so that each can kick the same particle an indefinite number of times and the resulting particle bunch is available for physicists to play with at will.

The size of an accelerator obviously depends in part on the number of cavities it contains. But it also depends on how close these cavities are together. And this is where the problem lies. The higher the flipping frequency and the stronger the electric field, the more tightly the cavities can be packed. But if the frequency is too high, and the voltage too strong, the copper will melt. The upshot is that the shortest distance copper cavities can realistically be placed apart is about 30cm.

Through a glass, briskly

With a bit of clever engineering, however, cavities of glass can be made to behave like copper ones, only better. In this case the alternating electric field is supplied by light which, being electromagnetic radiation, is actually just an electric field and a magnetic one leapfrogging one another at extremely high frequency. Crucially, though, whereas copper's limit is a frequency of a few gigahertz and a maximum field strength of 30m volts per metre, glass can manage frequencies of terahertz and field strengths of up to a billion volts per metre.

The American team, led by Robert Byer, of Stanford University, used this theory to create a system in which electrons are accelerated by laser pulses. The electrons fed into it were first sped up using a midsized standard accelerator, so when they arrived at the glass accelerator they were already travelling at 99.86% of the speed of light, or 60m electron-volts (an electron-volt being the energy gained by an electron moving across an electrical potential of one volt). That may sound a lot, but in high-energy physics it is small beer. Since nothing can travel faster than light, adding the remaining 0.14% would require an infinite amount of energy, which means there is plenty of scope for doing better.

Dr Byer did so by shunting the newly arrived electrons into a narrow channel between two glass plates, each half a millimetre long. Both plates had a line of teeth, each 400 nanometres across and 400 nanometres apart, etched onto their surface. Since, like real teeth in an upper and lower jaw, the positions of these glass teeth matched from plate to plate, the result was a series of microscopic cavities.

When electrons flew through the channel, Dr Byer arranged for them to be accompanied by pulses of infra-red light with a wavelength of 800 nanometres. That wavelength, being both twice the size of the teeth and of the distance between them, meant the phase of the light—and thus of its associated electric field—was rotated by 180° as it passed through each cavity. This rotation switched the voltage from positive to negative, or vice versa, as hap- ▸▸