Argonne physicists create landmark accelerator gradient

The Argonne Wakefield Accelerator (AWA) Group at the U.S. Department of Energy's Argonne National Laboratory works on particle accelerators in much the same way that horsepower junkies work on muscle cars. Although their research doesn't involve turbochargers, stall torque converters or cat back exhaust systems, the AWA group obsesses over the power of their machine.

Accelerator physicists Manoel Conde, Zikri Yusof, Richard Konecny and Felipe Franchini stand by the copper-based Argonne Wakefield Accelerator. The wakefield group recently broke the 100 MV/m benchmark for the strength of accelerating gradients by substituting an insulating dielectric for copper.

This past spring, Manoel Conde and his colleagues in the AWA group, led by physicist Wei Gai, crossed a major frontier in accelerator science: They generated an accelerating gradient five times stronger than that used in traditional linear accelerators. The gradient – a region of increasing electrical potential – works like an electrical "motor," transferring enormous amounts of energy to charged particles as they shoot through an accelerator. By substituting a dielectric for the copper medium used to support these accelerating electric fields, Conde and his colleagues generated a gradient of 100 MV/m; traditional linear accelerators generally cannot support a gradient higher than 20 MV/m.

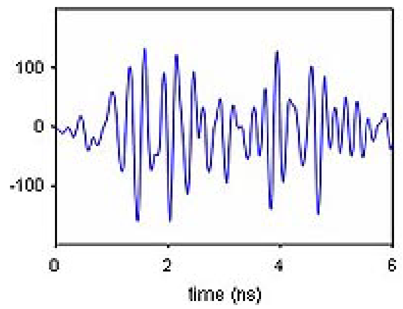
Higher gradients could allow for more compact accelerators with the same or greater energy as today's high-energy accelerators, which often stretch for miles. Aside from extending the energy frontier, high-gradient acceleration will allow for the miniaturization of the medium- and low-energy accelerators used in hospitals for radiation therapy, improving their accuracy while reducing their cost, Gai said.

High-energy physicists realize that they cannot continue their decades-long trend of building ever-longer accelerators, said John Power, a physicist in the AWA group. He sees projects like CERN's Large Hadron Collider, with a circumference of about 17 miles, or the proposed 20-to-25-mile-long International Linear Collider (ILC) as nearing the ceiling for an accelerator's physical size.

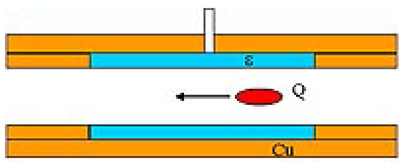
"Right now, high-energy physicists are building accelerators that are approaching practical limits in term of their length and cost," Power said. "We're pushing technology to the limit and accelerators are getting to be extremely long – to get to the next level we need to raise the gradient."

Physicists have started to look for ways to make accelerators more powerful. The limiting factor lies in finding a suitable alternative to the traditional copper accelerators that Power called "the workhorses of high-energy physics over the last 50 years."

Traditionally, copper-based accelerators have operated at gradients below approximately 20 MV/m. Recently, accelerator scientists developed an advanced copper accelerator and were able to achieve a gradient of 65 MV/m,



An oscilloscope picture showing no disruption of the wave signal, indicating that the high gradient did not cause the dielectric structure to break down.



A schematic of the new accelerator structure. The copper color represents the external copper structure, while the blue represents the new insulating dielectric used to produce the high gradients. The red disk in the center represents the electron bunch.

above which point the accelerator suffered irreversible damage, according to Power. It is believed that above this level the strong electric fields produce a phenomenon known as field emission, in which electrons circulating in the highly conductive metal get pulled out of the copper surface, generating discharges that can damage the accelerator.

In the quest to achieve a higher gradient, the AWA group turned to dielectrics – or insulating materials – as potential alternatives. "If dielectrics can support high gradients, we've got a great shot at a working accelerator," Power said. "The power sources and the size of the supporting structures are the same as that of traditional accelerators, which is a great strength of the dielectric scheme."

While Gai cautioned that other challenges still impede the realization of a high-gradient dielectric accelerator, he agreed with Power's observation. "This is one of several promising advanced technologies on the horizon, along with laser and plasma acceleration and various types of metallic-based accelerators," he said.

Unlike traditional accelerators, which employ only one particle beam, wakefield accelerators use two beams: a "drive beam" to create the high gradient and a "main beam" to be accelerated. Within the drive beam, one or several highly charged "bunches" of electrons are shot through the dielectric structure. Like a speedboat rushing over a lake, each drive bunch leaves behind an electromagnetic wake. The electric gradients produced by these wakes are then used to accelerate the main beam. By synchronizing the emission of each successive drive bunch with the wake's waves, Yusof explained, scientists can create stronger wakes that produce higher gradients.

Although the 100 MV/m figure constitutes a true landmark for accelerator physicists – "it's a milestone we've pursued for 10 years," Power said – dielectrics or similar materials could produce even higher gradients. The absolute upper bound on solid-based accelerators is believed to be on the order of 10 GV/m, above which point solids are expected to ionize and destabilize. That figure represents a 100-fold gain over the gradients AWA scientists have generated, leaving considerable room for later improvements.

Power believes that the successful construction of higher-gradient accelerators will precipitate a revolution, as high-energy physicists – the AWA's "primary customers" – will gain access to a whole new regime of energies. "Right now," he said, "the 20-mile ILC is expected to give you about half a tera-electronvolt (TeV) of energy. If you take the same 20 miles and apply high-gradient technology, you can get a couple of TeV and perhaps even more in the future. That opens up many different possibilities."

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