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Magnetic Field Record Set With a Bang: 1,200 Tesla

A field 400 times as strong as an MRI should reveal new physics of nanoscale materials

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Image: University of Tokyo

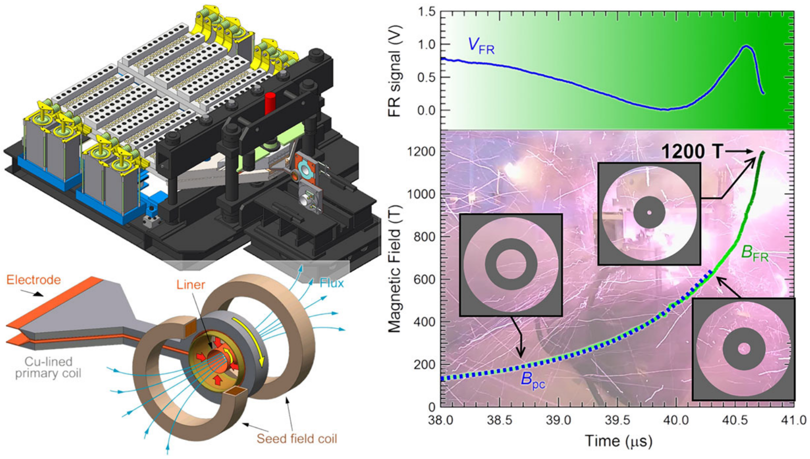
During 40 microseconds last April, Shojiro Takeyama and his team (https://www.issp.u-tokyo.ac.jp/maincontents/organization/labs/takeyama_group_en.html) at the University of Tokyo dumped 3.2 megajoules of energy into a newly built scientific instrument and blew part of it to smithereens. The smithereens part was expected; the force of the explosion, not quite. The instrument was designed to generate superstrong magnetic fields for examining semiconductors and other materials at the nanometer scale. Takeyama was expecting about 700 Tesla. He got 1,200 T instead—a world record for indoor fields (http://dx.doi.org/10.1063/1.5044557) and about 400 times as strong as a typical medical MRI.

Bigger magnetic fields have been made before, but they aren't practical or reliably reproducible, because they rely on rather dangerous amounts of TNT. It is not an indoor activity.

These fields are generated by starting with a strong, unchanging magnetic field and then rapidly—on the order of microseconds—squeezing it. Instead of causing that squeeze with a TNT-fueled implosion, Takeyama used an electrically induced one.

Image: University of Tokyo

The University of Tokyo's 1,200-Tesla magnetic field generator is powered by a bank of capacitors [top left, white] capable of storing 5 megajoules. The capacitors' energy flows into the primary coil [bottom left, gray] and induces a counteracting current and magnetic field in the liner [orange]. This implodes the liner in 40 microseconds, compressing the magnetic field [bottom right].



The setup looks like this: A set of coils produces a static magnetic field 3.2 T strong, or roughly equivalent to what you experience inside an MRI. At the center of this field is a single coil attached to a bank of capacitors capable of storing 5 megajoules when fully charged. Inside this "main coil" is what's called the liner. This is a lightweight copper tube not quite 12 centimeters across and only 1.5 millimeters thick.

On command, the capacitors release their charge into the main coil through 480 separate cables. The resulting current increases at an astounding 40 million amperes per microsecond and tops out at about 4 amperes. This massive flow sets up a magnetic field that induces a counteracting current inside the liner. The two currents produce magnetic fields that repel each other. However, the main coil is a relatively thick and heavily reinforced ring of copper-lined steel, and the liner is practically foil. You can guess which wins this fight. "Because of the difference in the mass inertia, the liner implodes inwards" at a rate of about 5 kilometers per second, explains Takeyama. As it does so, it compresses the 3.2 T field so that when the liner is at its smallest, the magnetic field inside it reaches 1,200 Tesla. Unable to be compressed any further, the liner rebounds at about the same rate it imploded, destroying itself and the main coil.

Video: University of Tokyo

Luckily, the machine sits in an iron cupboard to cushion the shock wave. Unfortunately, it wasn't quite strong enough. "I designed the iron housing to endure against about 700 T," says Takeyama. That was about 60 percent of what it actually delivered. "I didn't expect it to be so high." The enclosure door bent and broke. "Next time I'll make it stronger," he says, pointing out that everyone involved is in a separate control room and out of harm's way.

Shock waves and supersonic metal fragments aside, University of Tokyo's machine is the safest way to achieve the kinds of kilotesla-scale fields needed to discover new solid-state physics. In such a strong magnetic field, electron motion is confined to a space less than a nanometer across, allowing for new, more precise measurements. "In general, the higher the field, the resolution of measurement becomes better and better," says Takeyama.

The measurements will only get easier. Takeyama is working on making the measurement space a bit bigger—10 mm—to accommodate other instruments. Using the system's fully charged 5-MJ capacitor bank, that should lead to another record: 1,500 T.

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