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Researchers finding applications for tough spinel ceramic

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The U.S. Naval Research Laboratory uses a hot press to make spinel into conformable optics, like this flat sheet. "Ultimately, we're going to hand it over to industry," says Dr. Jas Sanghera, who leads the research, "so it has to be a scalable process." In the lab, they made pieces eight inches in diameter. "Then we licensed the technology to a company who was able then to scale that up to much larger plates, about 30-inches wide." Credit: U.S. Naval Research Laboratory/Jamie Hartman

Imagine a glass window that's tough like armor, a camera lens that doesn't get scratched in a sand storm, or a smart phone that doesn't break when dropped. Except it's not glass, it's a special ceramic called spinel {spin-ELL} that the U.S. Naval Research Laboratory (NRL) has been researching over the last 10 years.

"Spinel is actually a mineral, it's magnesium aluminate," says Dr. Jas Sanghera, who leads the research. "The advantage is it's so much tougher, stronger, harder than glass. It provides better protection in more hostile environments—so it can withstand sand and rain erosion."

As a more durable material, a thinner layer of spinel can give better performance than glass. "For weight-sensitive platforms-UAVs [unmanned autonomous vehicles], head-mounted face shields—it's a game-changing technology."

NRL invented a new way of making transparent spinel, using a hot press, called sintering. It's a low-temperature process, and the size of the pieces is limited only by the size of the press. "Ultimately, we're going to hand it over to industry," says Sanghera, "so it has to be a scalable process." In the lab, they made pieces eight inches in diameter. "Then we licensed the technology to a company who was able then to scale that up to much larger plates, about 30-inches wide."

The sintering method also allows NRL to make optics in a number of shapes, "conformal with the surface of an airplane or UAV wing," depending on the shape of the press.

In addition to being tougher, stronger, harder, Sanghera says spinel has "unique optical properties; not only can you see through it, but it allows infrared light to go through it." That means the military, for imaging systems, "can use spinel as the window because it allows the infrared light to come through."

NRL is also looking at spinel for the windows on lasers operating in maritime and other hostile environments. "I've got to worry about wave slap and saltwater and things like that, and gun blasts going off—it's got to be resistant to all that. And so that's where spinel comes into its own," says Sanghera.

Says Sanghera, "Everything we do, we're trying to push the mission. It's designed to either enable a new application, a new capability—or enhance an existing one."

What is spinel?

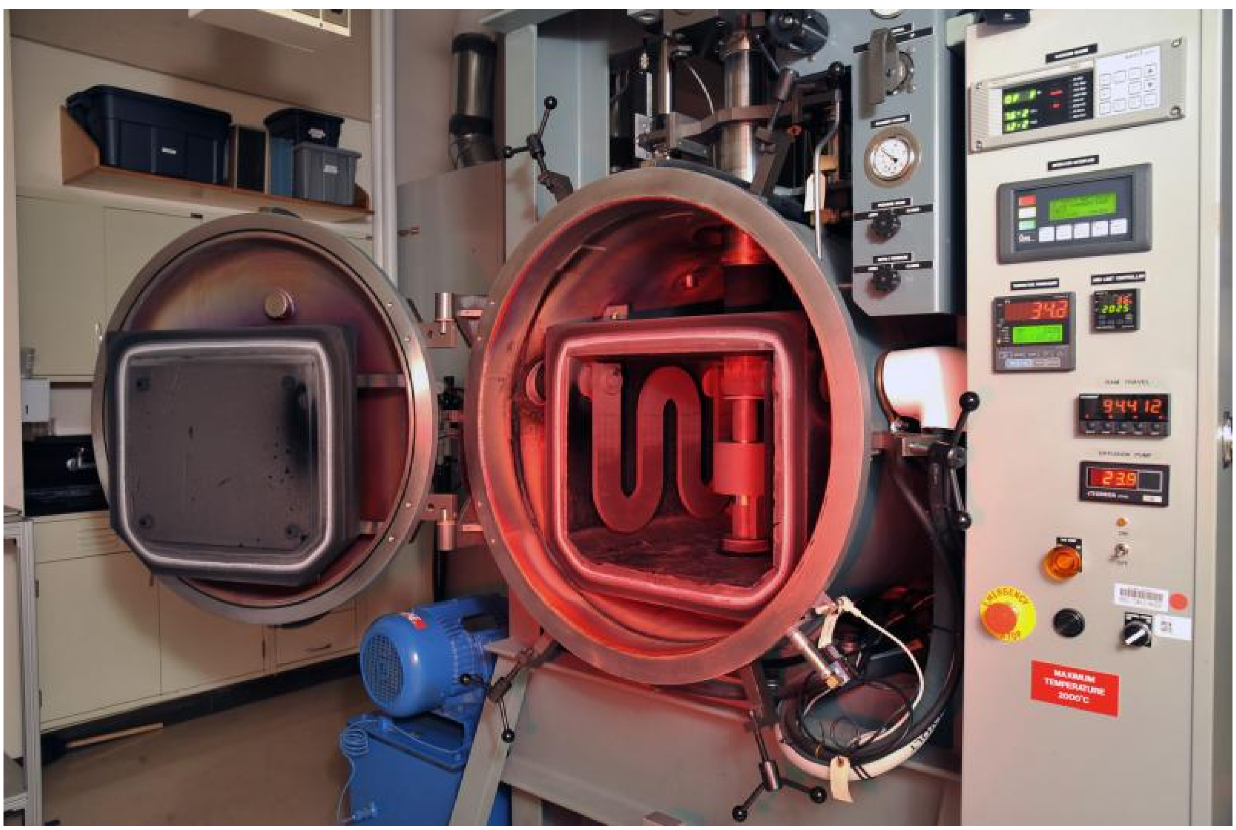
Spinel can be mined as a gemstone; a famous example is the Black Prince's Ruby, which is actually spinel with a color dopant. NRL chemists have also synthesized their own ultra-high purity spinel powder, and other synthetic versions are commercially available. "The precursors are all earth abundant, so it's available in reasonably low cost," says Sanghera.

The spinel NRL makes is a polycrystalline material, or a lot of crystal particles all pressed together. Whereas with glass, "A crack that forms on the surface will go all the way through," spinel might chip but it won't crack. "It's like navigating through the asteroid belt, you create a tortuous path: if I have all these crystals packed together, the crack gets deflected at the hard crystals: you dissipate the crack energy."

A manufacturing process that's transferable and scalable

When scientists first started trying to make glass-like spinel, they were using a crucible instead of a press. "A big problem with growing crystals is that you have to melt the starting powder at very high temperatures, over 2000 degrees Celsius," says Sanghera. It's expensive to heat a material that high, and additionally, "the molten material reacts with the crucible, and so if you're trying to make very high quality crystals, you end up [with a] huge amount of defects."

That's why Sanghera and his colleagues turned to sintering. "You put the powder in [a hot press], you press it under vacuum, squash this powder together—and if you can do that right, then you can get rid of all the entrapped air, and all of a sudden it comes out of there clear-looking."



The U.S. Naval Research Laboratory uses a hot press to make spinel, a process called sintering. It’s much less expensive than melting, and the size of the pieces is limited only by the size of the press. Says lead researcher Dr. Jas Sanghera, "You put the powder in [a hot press], you press it under vacuum, squash this powder together—and if you can do that right, then you can get rid of all the entrapped air, and all of a sudden it comes out of there clear-looking." To further increase the quality of the optic, "You can grind and polish this just like you would do gems." Credit: U.S. Naval Research Laboratory/Jamie Hartman

If the press has flat plates, the spinel will come out flat. "But if I have a ball and socket joint, put the powder in there, I end up with a dome shape," says Sanghera, "so we can make near net shape product that way."

NRL was not the first to try sintering. But previous attempts had yielded "a window [where] most of it would look cloudy, and there would be an odd region here and there—about an inch or so—that was clear, and that would be core-drilled out."

So NRL deconstructed the science. They started with purer chemicals. "Lousy chemicals in, lousy material out," says Sanghera.

Then they discovered a second problem, with the sintering aid they were adding to the spinel powder. "It's about one percent of a different powder, in this case lithium fluoride," says Sanghera. This "pixie dust" is meant to melt and "lubricate the powder particles, so there's less friction, so they can all move together during sintering." They were putting the powders together in shakers overnight, but, "The thing is, on a scale of the powder, it's never mixed uniformly."

Understanding the problem led to a unique solution for enabling uniform mixing. Now, "there's only one pathway for densification," and the spinel will come out clear across the press.

To further increase the quality of the optic, "You can grind and polish this just like you would do gems," says Sanghera. This is the most costly part of the process. "One of the things we're looking at is, how do we reduce the finishing cost?" The surface of the press is imprinted onto the glass. "If we can improve upon that," he says, "make that mirror finished, then—and so that's where we get into a little bit of IP [intellectual property], is what's the best way to do that?"

For both the Department of Defense (DoD) and private industry, "Cost is a big driver, and so it's important for us to make product that can be affordable."

Unique applications for military and commercial use

"There are a lot of applications," says Sanghera. He mentions watches and consumer electronics, like the smart phone, as examples.

The military in particular may want to use spinel as transparent armor for vehicles and face shields. A "bullet-proof" window today, for example, has layers of plastic and glass perhaps five inches thick. "If you replaced that with spinel, you'd reduce the weight by a factor of two or more," says Sanghera.

The military's also interested in using spinel to better protect visible and infrared cameras on planes and other platforms. Glass doesn't transmit infrared, so today's optics are made of "exotic materials that are very soft and fragile," and have multiple layers to compensate for color distortions. "So that's what we've been doing now, developing new optical materials," says Sanghera. Spinel windows could also protect sensors on space satellites, an area Sanghera's interested in testing.

"You could leave these out there for longer periods of time, go into environments that are harsher than what they're encountering now, and enable more capabilities," he says."

A technician cleans an infrared camera from the deck of the USS Cleveland (LPD 7). The U.S. Naval Research Laboratory (NRL) is making transparent ceramics, called spinel, that could one day replace the glass in military imaging systems. In maritime and other hostile environments, "I've got to worry about wave slap and saltwater and things like that, and gun blasts going off," says optical scientist Dr. Jas Sanghera. "And so that's where spinel comes into its own." In addition to being tough, spinel has "unique optical properties; […] it allows the infrared light to come through." Credit: U.S. Navy/Mass Communication Specialist 2nd Class Michael Russell

NRL is also looking at spinel (and other materials) for next generation

(NEXTGEN) lasers. "Lasers can be thought of as a box comprised of optics," he says. "There's passive and there's active components: passive is just a protective window; active is where we change the color of light coming out the other end."

For passive laser applications, like exit apertures (windows), the key is high quality. "That window, if it's got any impurities or junk, it can absorb that laser light," says Sanghera. "When it absorbs, things heat up," which can cause the window to break. Sanghera and his colleagues have demonstrated, working with "ultra high purity" spinel powder they've synthesized in NRL clean rooms, spinel's incredible potential.

For active laser applications, they've demonstrated how sintering can be used with materials other than spinel to make a laser that's "excellent optical quality." Instead of spinel, they use, "things like yttria or lutecia [and] and dope them with rare earth ions."

NRL has transitioned both types of laser materials and applications to industry.

What makes NRL tick is solving problems

Sanghera came to NRL in 1988, after completing his PhD at the Imperial College, London in materials science. "Little by little—talking to people, asking questions, going to conferences—you find out that what makes this place tick is solving problems," he says. "No two days are the same, it's very exciting."

The U.S. Naval Research Laboratory (NRL) presses spinel powder into transparent domes, sheets, and other shapes. "For weight-sensitive platforms—UAVs, head-mounted face shields—it's a game-changing technology," says Dr. Jas Sanghera, who leads the research. If the press has flat plates, the spinel will come out flat. "But if I have a ball and socket joint, put the powder in there, I end up with a dome shape." Credit: U.S. Naval Research Laboratory/Jamie Hartman

He first worked with glass, drawing it into optical fibers, and a lot of his success with spinel comes from that heritage of insisting on purity and quality. "An optical fiber's very long: it can go from 1 meter to 100s of kilometers. Purity's very important, because if there's any junk in there, the light will either be absorbed or it can be scattered."

His lab also makes lightweight, inexpensive fibers for infrared countermeasures applications on helicopters and other platforms. By weaving it through the platform, "This fiber can remote the energy from the laser, which is inside the platform, to a device on the outside, which can then track and then shoot the laser beam out, confuse the missile."

He acknowledges, "In DoD, we are the premier place for development of fiber lasers. It's something we are heavily involved with, all the different types of fibers and configurations and materials required to enable these eye-safer and NEXTGEN lasers."

Sanghera says that there's evolution, like enhancing an existing capability by improving size, weight, and performance/power (SWAP); "But revolution is when you come up with some new idea, you just enabled completely new capabilities." For that, he credits the many different disciplines NRL brings together. "We have a lot of smart people, we have a lot of what I call head-banging sessions, where we discuss new ideas and opportunities. If you don't ask the questions, you won't get answers and you won't stimulate new ideas."

He also credits a close relationship with industry and with those NRL serves. "We talk to the warfare centers, the systems people—so that what you're doing really is going to be of value. There's already the application there in mind, and we're just trying to solve that problem; so it's very focused in that sense."

Provided by Naval Research Laboratory

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