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ALON and spinel excel as infrared optical materials

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ALON and spinel, two transparent ceramics used in IR optics, each exhibit a unique combination of properties; a comparison allows the optical engineer to select the right material for the job.

The two infrared (IR) optical materials aluminum oxynitride (termed ALON by Surmet), which has a cubic spinel crystal structure, and magnesium aluminate spinel (commonly called spinel) possess several desirable and unique properties.[1] Chief among them are durability, chemical resistance, high hardness, and high strength, along with broadband spectral transparency (UV through mid-wave IR).

Although the materials have been studied in laboratories for decades, they have only recently become commercially available (see Fig. 1). Growing interest in the defense and optics industries has driven the market for these materials in recent years. Moreover, their combination of mechanical and optical properties makes them extremely attractive in many other areas.

Both materials look the same as glass, so what is so special about ALON and spinel? There are several facets to the answer. First, ALON and spinel transmit over a broader range of wavelengths; they are transparent in spectral regions where glass is as opaque as steel. Second, their excellent mechanical properties provide them with extreme environmental durability, making them about ten times more abrasion resistant than glass. They also survive much higher temperatures and more aggressive chemical environments than glass can withstand.

Another transparent ceramic material, sapphire (alumina in single-crystal form), is also hard, durable, and transparent. So what makes ALON and spinel different from sapphire? In order to be transparent, sapphire must be grown as single-crystal boules or sheets, and subsequently cut, ground, and polished into final components. On the other hand, by virtue of their cubic crystal structure, ALON and spinel are transparent in their polycrystalline form, allowing them to be produced using conventional

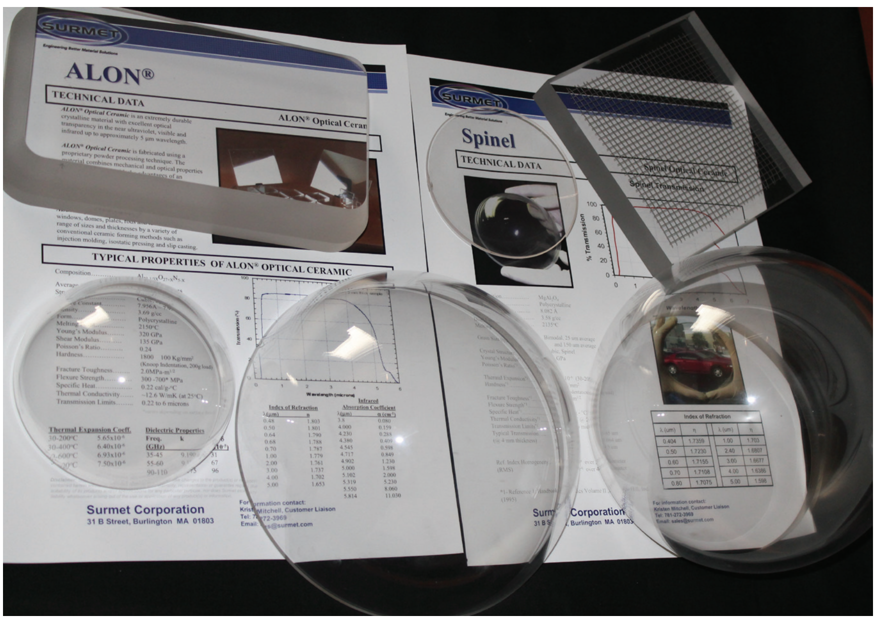

FIGURE 1. Examples of ALON and spinel components produced by Surmet are shown, including a component with a metal grid incorporated into it (upper right). *(Courtesy of Surmet)*

Table 1. **Key properties of ALON and spinel**[2,3]

Property	ALON	Spinel
Strength (MPa)	300–700	70–300
Hardness (kg/mm^2, Knoop)	1800–1870	1550–1650
Refractive index (at wavelength 0.5 μm)	1.80	1.723
Transmission wavelength range (@ 2 mm thick)*	0.25 to 6	0.25 to 6.5
Refractive index in-homogeneity (~4 in. aperture, RMS)	~5	<10
Transmittance* (%)	84–85	80–86
Haze* (%)	<2	<10
Clarity* (%)	>98	>95

*Varies depending on processing conditions and thickness

powder-processing techniques.

Sapphire is also limited by its very slow growth rates (on the order of 18 days to grow a 100 kg boule), and the inability to produce complex shapes and large sizes (current maximum size is about 16 in. wide). Given the high hardness of sapphire (next to diamond on Moh's scale of hardness), carving final components from these boules is a very slow and expensive proposition.

In contrast, ALON, which also has a hardness close to that of sapphire, and spinel are made using powder processing: here, the component's basic shape, called a "green body," is formed from powder using commonly used techniques such as slip casting, injection molding, and cold isostatic pressing. The green body has the consistency of chalk and is only about 50% dense, with substantial porosity. Green bodies are typically strong enough to handle, but weak enough to break by hand. The green body is then subjected to a series of heat-treating steps, which bring it to full optical density (transparency) and full strength. The powder-processing route allows these materials to be produced in large sizes and more-complex geometries than are possible—or at least practical—with single-crystal sapphire.

ALON and spinel optical ceramics are not cheap alternatives to single-crystal sapphire, but rather better solutions for applications that require large-sized or complex-shaped components. Another unique feature that powder processing facilitates is the ability to embed metallic architectures within a component and yet preserve the transparency (for example, the square tile in the upper-right-hand corner of Fig. 1).

Manufacturing ALON and spinel

There are very few manufacturers across the world with the capability to manufacture transparent polycrystalline ceramics commercially. For example, Surmet is the only commercial

Table 2. **Some current and potential applications of ALON**[3]

Enabling feature/ property	Applications
Strength •Hardness •Chemical resistance •Durability	*Transparent armor:* ALON is the best transparent armor material that exists today. ALON provides state of the art ballistic performance against advanced threats, including .50-caliber armor-piercing rounds, at half the weight and thickness of glass armor. *Durable transparencies:* Being one of the hardest ceramic materials, ALON provides significant scratch resistance and environmental durability (rain and sand erosion resistance). Applications such as windows for laser communications (airborne laser data links, counter MANPADS, laser rangefinders, laser target designators, laser radars, etc.), protective covers for sensors, pressure vessels, laser igniter windows, etc. *Covers for handheld devices and electronics:* Because of its high hardness, ALON screens will be literally scratch-proof.
Mid IR transmittance High refractive-index homogeneity Low transmitted wavefront error	*Infrared optics:* Tri-mode seeker domes and hyper-hemispherical domes are used on infrared missile and countermeasure systems. *Reconnaissance and sensor windows:* On helicopters and aircrafts; large ALON windows are available with excellent refractive-index homogeneity and transmitted wavefront uniformity. *Night-vision systems:* ALON-based transparent armor systems provide significant advantages over glass-based armor due to its high transmittance in the 0.6 to 1 micron wavelength range (typical night-vision systems operating wavelengths)
RF transparency	High-power RF accelerator windows
Embedded architectures	*Multifunctionality:* Sensors or antennas embedded in transparent armor windows, electromagnetic shielding, additional ballistic performance, porous channels for fluid passage, etc.
Chemical and plasma resistance	Semiconductor equipment, plasma-etching chambers, etc.

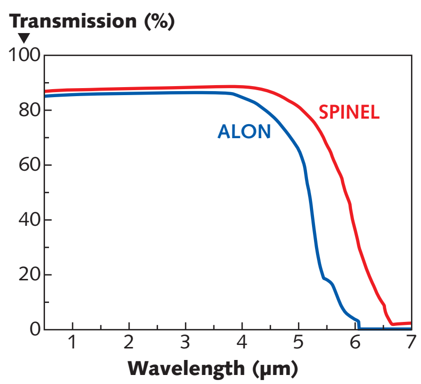

FIGURE 2. Transmission spectra of ALON and spinel are compared (2 mm thick, without antireflection coatings).

supplier of ALON components and one of a small number of companies globally that produce and supply spinel transparent ceramic components. Currently, there are no reliable suppliers for spinel components in large sizes and quantities. Spinel components are manufactured using one of two approaches: sinter/hot isostatic pressing (sinter/HIP) and lithium fluoride (LiF)-doped hot pressing/HIP. Surmet uses the classic solid-state sinter/HIP approach for both ALON and spinel components. Some studies have shown sinter/HIP parts that are mechanically superior to LiF-doped hot pressing/HIP based parts.[4,5]

Manufacturing of ALON and spinel components rely on powder-processing techniques similar to those used for other ceramic materials; however, the requirement for transparency introduces some additional challenges. These include the control of powder synthesis to produce starting powder with very high purity (even part-per-million-level impurities can lead to tint and possibly opacity) and the requirement to reduce porosity to less than 0.1%. Additionally, transparent ceramic components must go through grinding and polishing in order to achieve transparency. This all becomes even more challenging for components with complex geometries.

FIGURE 3. Examples of ALON transparent ceramic components and their applications (top row: transparent armor; middle: sensor and reconnaissance windows; bottom: mid-IR optics for missiles and countermeasures). *(Courtesies: Left column: Surmet. Middle: Joe Bullinger, U.S. Navy (top); U.S. Air Force photo/ Matt Hecht (middle); Julianne Showalter, U.S. Air Force (bottom); and Right: Bengt Oberger (top); Brian Fleske, U.S. Navy (middle); Looper5920 (bottom). Middle and right columns via Wikimedia Commons.)*

Key properties and applications

Some of the key properties of ALON and spinel optical ceramics are given in Table 1. As seen, ALON has superior mechanical properties. Commercially available ALON products are known for their optical quality, including low haze, high clarity, refractive-index homogeneity, and lack of inclusions. Spinel components manufactured using LiF-doped hot pressing/HIP approach, on the other hand, are known to have high haze.

As seen in Figure 2, Spinel has extended spectral transmission in the mid-IR wavelength range as needed for some mid-IR optics and sensor applications. However, in certain cases where spinel is not readily available in large sizes, ALON is being considered as an available and producible alternative. ALON is also being considered for a broader range of applications because of the combination of its superior mechanical properties and producibility. Examples of applications for ALON components are shown in Table 2 and Figure 3.

As these materials are produced in higher volumes to satisfy critical defense needs, production costs will be driven lower. The combination of higher-volume manufacturing and lower costs will make them applicable to a wider range of more cost-sensitive applications including semiconductor-processing equipment and durable covers/windows for handheld electronic devices.

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