

# Transparent Ceramics Enable Large, Durable, Multifunctional Optics

Aluminum oxynitride and magnesium aluminate spinel are mechanically strong, hard and scratch resistant; they are also chemically durable. Both exhibit broadband transmittance from near-UV to mid-IR.

BY MOHAN RAMISETTY, LEE GOLDMAN,  
NAGENDRA NAG, SREERAM BALASUBRAMANIAN  
AND SURI SASTRI, SURMET CORP.

**Single-crystal sapphire** has been the material of choice for defense and other applications that require extremely durable optics, but aluminum oxynitride (ALON) and magnesium aluminate (spinel) have emerged for use when those applications need optics in large sizes or with complex geometries.

Table 1 lists the key physical properties of each material. Both have cubic spinel crystal structures that make them transparent in their polycrystalline form, which means they can be produced using conventional ceramic powder processing techniques. Powder processing allows them to be produced in large sizes, complex ge-

ometries and large volumes that otherwise would be very difficult or impossible.

While their crystal structures are similar, some of their mechanical and optical properties are different. ALON's high hardness, modulus and strength are especially suited for transparent armor; spinel's extended transmission in the mid-infrared wavelength region (Figure 1) makes it applicable for many IR optics uses.

#### How they are made

The manufacturing processes for ALON and spinel are similar to the processes used for any other ceramic materials. However, because these materials need to be trans-

parent, purity and process control are quite a bit more challenging. Between the two, the ALON process is much more robust, has higher yields and produces parts of better quality compared to spinel.

Unlike single-crystal sapphire, versatile ceramic green-forming techniques allow ALON and spinel components to be formed into near-net shapes prior to heat treatment, saving energy and significantly reducing machining costs. The processing steps (Figure 2) for both materials involve:

- (1) Powder synthesis.
- (2) Green body formation (shaping).
- (3) Heat treatment.
- (4) Optical fabrication.

**Table 1. Key properties of ALON and spinel.**

| Property   | ALON   | Spinel                    | Unit               |
|--|--|---------------------------|--------------------|
| Chemical Formula   | $\text{Al}_{23-1/3x}\text{O}_{27+x}\text{N}_{5-x}$ | $\text{MgAl}_2\text{O}_4$ | -                  |
| Density  | 3.69   | 3.58                      | g/cc               |
| Flexure Strength   | 300 to 700   | 70 to 350                 | MPa                |
| Knoop Hardness   | 1870   | 1650                      | Kg/mm <sup>2</sup> |
| Refractive Index (at Wavelength 0.5 $\mu\text{m}$ )        | 1.80   | 1.723                     | -                  |
| Absorption Coefficient (at 3.39- $\mu\text{m}$ Wavelength) | 0.1  | 0.018                     | $\text{cm}^{-1}$   |
| Transmission Wavelength Range*                             | 0.25 to 6  | 0.25 to 6.5               | microns            |
| Refractive Index Homogeneity (~4-in. Aperture)             | ~5   | <10                       | ppm                |
| Typical Haze (in the Visible Range)*                       | <2   | <10                       | %                  |
| Typical Optical Clarity (in the Visible Range)*            | >98  | >95                       | %                  |

\*Varies depending on thickness and processing conditions.

Green bodies can be created by one of a number of forming methods, including cold isostatic pressing, die pressing, injection molding and slip casting. Green bodies have the consistency of chalk and are only partially dense. They are then subjected to a number of heat treatment steps which bring them to full optical transparency. Commercially available ALON components are made using sinter/hot isostatic pressing (HIP) processes. They are virtually inclusion free and generally known for their high optical clarity, low haze, being tint free and – most importantly for many critical applications such as reconnaissance and sensor windows – good refractive-index homogeneity over large areas. Spinel can also be produced using the same basic heat treatment approach.

Another production method for spinel components uses a uniaxial hot pressing followed by hot isostatic pressing (HP/HIP) approach. In this process, a liquid phase sintering aid such as LiF is generally needed. Unfortunately, many studies have shown that the LiF-based approach leads to serious grain-boundary weakness issues, resulting in low strength and also problems in attaining a high level of RI homogeneity.

**Complex geometries, multifunctional features**

Optical ceramic components with complex 3-D geometries are required for many applications, including infrared (IR) military optics. Hemispherical and hyper-hemispherical domes, tangent ogive domes, complex lenses and curved windows are some of the complex geometries possible with powder-based ALON and spinel optical ceramics (Figure 3). Applications that use such components include tri-mode (laser, IR and radiofrequency) seeker systems, IR countermeasure systems and aircraft-targeting pod systems.

Manufacturing components with such complex geometries from single-crystal sapphire is uneconomical because of the costs involved in growing boules and subsequent machining of these shapes from the boules. Like sapphire, ALON and spinel ceramics still need grinding and polishing, but their near-net shape formability in the green stage eliminates huge machining/optical fabrication costs.

Embedded internal architecture within ALON optical ceramic components offers

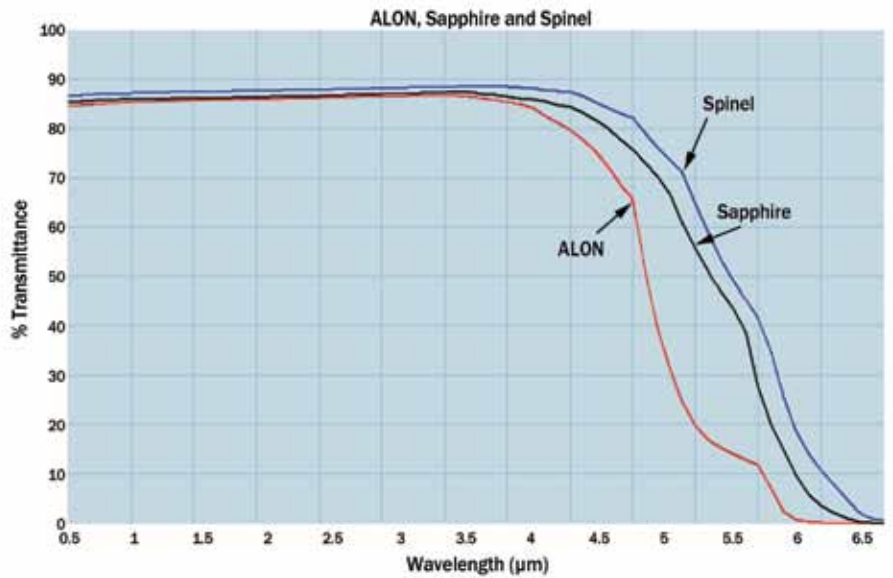


Figure 1. Transmittance spectra of ALON, spinel and single crystal sapphire at 2-mm thickness (without antireflection coatings).

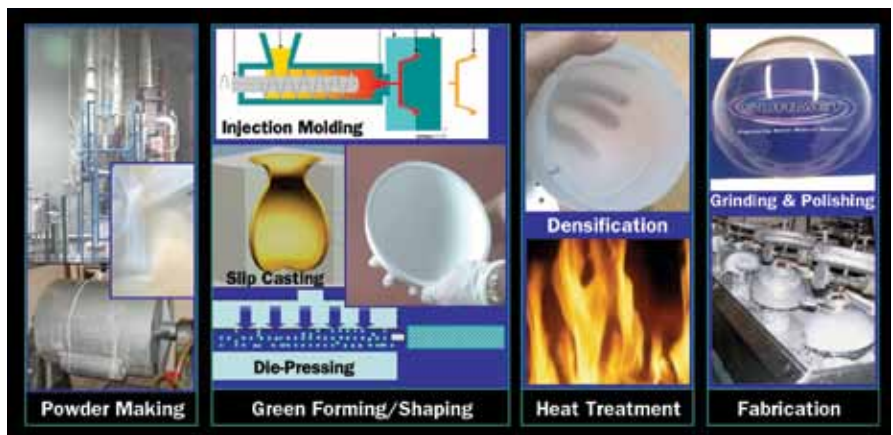


Figure 2. Typical process steps involved in manufacturing ALON and spinel transparent ceramics.

the potential for additional functionality. Some examples of multifunctional components are (Figure 4):

- Domes or windows with embedded grids or meshes for EMI (electromagnetic interference) shielding.
- Domes or windows with embedded antennas.
- Domes or windows with built-in recesses and internal electrical connections for sensors.

Additionally, compliant and integrated internal structures can be tailored to en-

hance mechanical properties such as toughness, structural integrity or ballistic performance of the component.

**ALON-based GRIN optics**

Although polymer and glass-based gradient index (GRIN) optics have been around for quite some time, ALON-based GRIN optics are relatively new and currently under development in a DARPA-funded research program at Surmet. GRIN-based lenses have a refractive index profile that varies gradually within the material in a controlled fashion. In compari-



Figure 3. Examples of ALON and spinel components with complex geometries.

Powder-processing methods allow ALON/spinel components to have complicated geometries and/or internal architectures.

son to regular lenses, which depend upon curvatures machined into their surfaces to bend light, GRIN optics can also use controlled gradients within the material itself to bend the light. This can be used with or without surface curvature to produce lenses.

This additional control can lead to substantial miniaturization and weight reduction in optical systems as well as reduction in optical aberrations caused by spherical lenses.

# ICALLEO®

33<sup>rd</sup> INTERNATIONAL CONGRESS ON APPLICATIONS OF LASERS & ELECTRO-OPTICS

## SAVE THE DATE!

Sheraton® San Diego • San Diego, CA USA

October 19-23, 2014

ICALLEO® brings together the leaders and experts in the field of laser materials interaction, providing the world's premier platform for sharing new ideas and discovering breakthrough solutions.

Presented by:



**Laser Institute  
of America**

*Laser Applications and Safety*

[www.icaleo.org](http://www.icaleo.org)





When the refractive index varies through the thickness of a lens, it is called axial gradient. Typical applications of such lenses include photographic objectives, because of their significantly low chromatic aberration compared to aspheric lenses. The index profile can also be varied radially (Figure 5), and this type of lens offers both aberration correction and the ability to change the focal length of the lens. ALON-based GRIN optics can be fabricated with significantly large refractive-index gradients ( $\Delta n$ ), ranging up to 0.04 in both axial and radial profiles. This is achievable in ALON either by changing the composition and/or by adding suitable dopants.

Unlike many glasses and polymers, which are only transparent in visible wavelengths, ALON GRIN lenses are transparent in the visible- through mid-IR range. Furthermore, they offer exceptional du-



Figure 4. Examples of ALON components with embedded internal architectures.

Since 1993  
Top Quality  
Prototype to  
Production  
Quick Delivery  
Great Prices



Prototypes in 1-3 weeks

*When you say 'Jump', we take it very, very seriously*

# ARGYLE

The American Corporation with its own Factory in China

LightPipes  
Lenses  
Prisms  
Windows  
Mirrors  
Assemblies  
IR-VIS-UV



Argyle International Inc.  
254 Wall Street, Princeton, NJ 08540  
Tel: 609-924-9484 Fax: 609-924-2679  
www.ArgyleOptics.com

# Laser Light Engines

More than 25 different wavelengths between 355 and 1064nm available

**SOLE**  
SOLE - Laser Light Engine with up to 6 wavelengths and 2 fast switchable fibre ports

**LightHUB**  
LightHUB - Compact Laser Combiner with free-space or fibre coupled output of up to 6 wavelengths



**omicron**  
LASERAGE

Omicron-Laserage Laserprodukte GmbH  
www.omicron-laser.de, mail@omicron-laser.de  
Tel.: +49 61 06 / 82 24 - 0

robability in terms of scratch resistance, strength and high temperature resistance over glasses and polymers. This opens up many other potential applications for ALON GRIN lenses such as image systems for laser range finders, night-vision goggles and unmanned aerial vehicles.

**Meet the authors**

Mohan Ramisetty, Nagendra Nag and Sreeram Balasubramanian are part of the Advanced Materials R&D Group at Surmet Corp. in Burlington, Mass.; email: mramisetty@surmet.com. Lee M. Goldman is the CTO of the Optical Ceramics Division at Surmet; email: lmgoldman@surmet.com. Suri Sastri is the founder, chairman and CEO at Surmet; email: ssastri@surmet.com. The authors would like to acknowledge support from Mark Smith, Uday Kashalikar and Santosh Jha.

**References**

1. Mohan Ramisetty et al (2013). Transparent polycrystalline cubic spinels protect and defend. *American Ceramic Society Bulletin*, Vol. 92, No. 2, pp. 20-24.
2. Daniel C. Harris (1998). Durable 3-5µm

- transmitting infrared window materials. *Infrared Physics and Technology*, Vol. 39, pp. 185-201.
3. Nagendra Nag et al (2013). Multi-functional windows. *Proc. SPIE 8708, Window and Dome Technologies and Materials XIII*, 87080B (June 4).

4. Lee M. Goldman et al (2011). ALON optical ceramic transparencies for window, dome and transparent armor applications. *Proceedings of SPIE*, Vol. 8016.
5. D.T. Moore (1995). Ch 9: Gradient Index Optics, *Handbook of Optics*, Vol. 2.

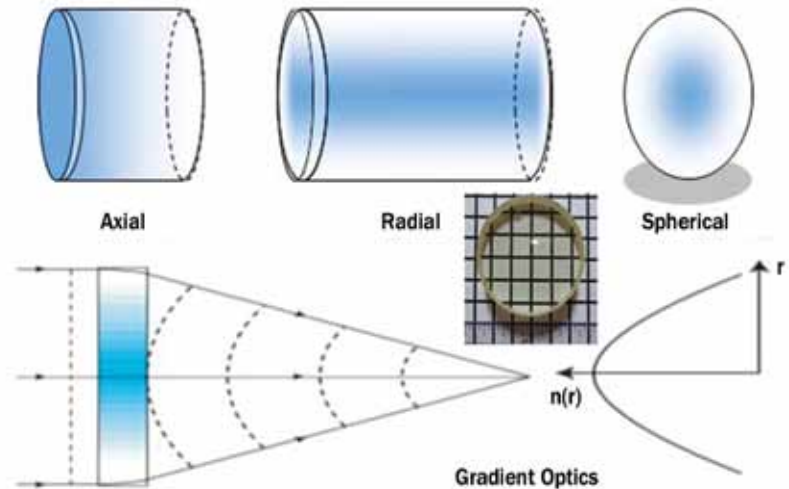


Figure 5. Graphical illustration of GRIN profiles (an ALON GRIN sample is shown in the inset).

**nanoscribe**

Nanoscribe's 3D printing systems allow the fabrication of nano- and microstructures by means of two-photon polymerization. The systems are used for a variety of research and development tasks in science and industry worldwide.

**Photonic Professional  $\equiv$  GT**  
Customer-oriented solutions for R&D

- Highest resolution in 3D printing
- Freedom in design for highly complex microstructures
- Broad range of compatible photopolymers
- 3D printing workflow for easy processing
- Multitude of applications, e.g. micro-optics, high-aspect ratio structures, photonic wire bonds

PRISM AWARDS WINNER

Nanoscribe GmbH  
Fon: +49 721 60 82 88 40  
info@nanoscribe.de  
www.nanoscribe.de

# Laser Shutter Safety Interlocks

Laboratory, Instrument, Industrial Applications

Our patented technology features a single flexing blade element to eliminate reliability concerns. Failsafe closure. Can be controlled with simple DC circuits. Internal beam dump. Position sensors independent of the power circuit verify open or close. Full feature interlock controllers, single and multi-output.

**nmLaser Products, Inc.**  
The Source for Laser Shutters

337 Piercy Road  
San Jose, CA 95138  
www.nmlaser.com

tel: 408-227-8299 • fax: 408-227-8265 • sales@nmlaser.com