Technical Note

Spectralon Reflectors as Laser Cavity Pumping Chamber Reflectors

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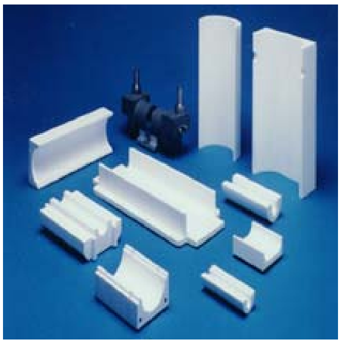
Introduction



Laser Grade Spectralon from Labsphere is a thermoplastic with diffuse, high reflectance which promotes increased powers and improved beam quality when used as a cavity reflector in lamp and diode pumped solid state lasers and lamp pumped dye lasers. Spectralon's combination of high reflectance (for example, >99% in the pump band of Nd:YAG at 808nm) and near-perfect diffuse reflectance provides laser engineers with a solution to the conflicting design objectives of high output energies combined with a high beam quality with reduced hot-spots.

Independent tests have shown that a flashlamp pumped Nd:YAG laser equipped with a Spectralon cavity reflector exhibits a 30% increase in slope efficiency and output energy compared with the same laser fitted with a ceramic chamber. This gain results from the multiple reflections that take place within the chamber, amplifying the effects of differences in the reflectance of the pumping chamber.

Laser output power and energy are not always the most important considerations for laser designers. For many applications in materials processing and scientific research, the quality of the laser beam is a priority. A laser equipped with a Spectralon cavity provides a significantly enhanced and more predictable beam quality compared with less diffusely reflecting materials as a direct result of the more uniform pumping of the laser medium. The laser output parameters that are affected include: improved spatial uniformity; reduced non-symmetrical optical aberrations (coma and astigmatism); and reduced 'hot-spots'. At the same time, a diffuse reflector will suffer from a much reduced risk of parasitic oscillations, allowing the designer to exploit the full output potential of the laser.

Spectralon is a thermoplastic that is machined according to customer-supplied drawings. Pro-Lite welcomes enquiries for customised fabrication of laser cavity reflectors which are produced in the company's dedicated Spectralon machine shop.

Extract from Big Sky Laser Corporation Test Report

The following information is an extract with summary conclusions from a report produced by Big Sky Laser Corporation on the performance of Labsphere Spectralon as a pumping chamber reflector material in optically pumped solid state lasers.

The use of Spectralon as a replacement for traditional materials used as laser cavity reflectors was first proposed in the early 1990s. Labsphere at that time identified this market opportunity and worked with the specialist laser consultancy firm Big Sky Laser (Bozeman, MT) to generate applications data to quantify the gains in laser performance that might result from using Spectralon. The Big Sky Laser (BSL) report also provides practical advice to designers considering the use of Spectralon.

BSL refer to a 'Generic Pump Cavity' (**GPC**): this is their proprietary, flashlamp pumped, pulsed Nd:YAG laser with a close-coupled Spectralon cavity reflector, which they describe as having been designed for maximum pump efficiency. This featured a 'race-track' cross section (think of this as a squashed ellipse or a rectangle with semi-circular ends). The report compares and contrasts the performance of the GPC with two, alternative designs:

- **KPC** – a commercially available flashlamp pumped, diffuse Nd:YAG cavity, assumed to be from Kigre Inc, and therefore of circular cross section using packed $BaSO_4$ powder reflector within a quartz tube.
- **SPC** – a flashlamp pumped Nd:YAG cavity with elliptical, specular reflector, assumed to be gold.

Tests performed on the three laser cavities were intended to quantify their relative optical performance. The parameters investigated by BSL were: **optical distortion** in the Nd:YAG laser rod measured as a function of average pump power determined using a Fizeau interferometer; **pumping uniformity** determined by viewing the distribution of fluorescence from the end of the laser rod with a CCD camera; **lasing efficiency** of the cavities installed within a laser resonator, determined using a laser power meter; and **laser beam quality** assessed using a CCD-based beam profiler.

It should be noted that the three types of cavity tested by BSL were not identical, in addition to the obvious difference in the material used as the cavity reflector: the cavities also differed in other respects. It should be remembered that BSL was primarily interested in promoting its GPC design, that used Spectralon, rather that simply singing the praises of the Labsphere material. Therefore, one may regard the BSL results as indicating the possible improvements in laser system performance that might result from the use of Spectralon but it would not be prudent to use this data to quantify the exact gain.

Optical Distortion: GPC vs. KPC

The spherical wavefront error (or power) relates to the radially symmetric pump power absorbed by the laser rod. In laser system design, the presence of spherical aberrations (called, generically, rod lensing) can, if required, be corrected using simple collimating optics. The presence of non-symmetric (astigmatic or comatic) distortions arising from non-uniform pumping of the Nd:YAG rod are undesirable.

BSL reported that the KPC exhibited an approximately 1.5 to 2 times greater non-symmetric wavefront error for the same pump power compared with the GPC. This can be partly attributed to the less uniform illumination of the Nd:YAG rod in that cavity design, although differences in the cooling of the KPC cavity will also have contributed to the distortions. The degree of rod lensing is somewhat influenced by the use of a UV absorbing filter placed between the lamp and rod in the KPC design: the UV radiation from the flashlamp in the KPC is mostly absorbed in the filter and is therefore not available to contribute to the heating of the laser rod.

The Strehl ratio for a perfect optic (that is, one that does not exhibit any aberration) is unity. BSL was able to plot the Strehl ratio for the two cavities as a function of input power, and after removing the spherical wavefront distortion from the equation, showed that the non-symmetric aberrations for the KPC lead to a Strehl ratio 2 – 3 times larger than for the GPC.

Conclusion*: the GPC exhibited a more uniform pumping of the laser rod compared with a packed $BaSO_4$ reflector, which leads to significantly reduced non-symmetric wavefront aberrations (astigmatism and coma) from a laser equipped with a Spectralon reflector.*

Pump Uniformity: GPC vs. SPC

Measurement of the fluorescence (spontaneous emission) emanating from the end of the Nd:YAG rod when illuminated by the flashlamp can be used to obtain a qualitative measure of the gain uniformity within the rod, and hence the extent to which the flashlamp radiation is uniformly coupled into the rod. BSL recorded profiles of the fluorescent emission for both the GPC and SPC at various pump levels.

BSR reported that the GPC produced much more uniform gain profiles compared to those from the SPC at all pump levels. As might be expected, the emission from the SPC was highest from the centre of the Nd:YAG rod, whereas the emission from the GPC was more uniformly distributed.

In a close-coupled cavity (like the GPC), the flashlamp directly illuminates one side of the laser rod. This leads to an increased asymmetry in the fluorescent emission as the pump power increases. BSR reported that the performance of a close-coupled, diffusely pumped Nd:YAG laser was dependent on the spacing between the rod and flashlamp: the closer the spacing, the more efficient the pumping, but at the expense of pump beam uniformity. To demonstrate this effect, BSR constructed a second GPC type cavity that used a circular cross section (instead of the race-track shape). This increased the rod to lamp spacing compared to the standard GPC and BSR saw a marked improvement in the uniformity of the fluorescent emission. However, the circular GPC cavity was much less efficient.

Conclusion: *the GPC cavity exhibited a much more uniform pumping of the laser rod compared with the specular cavity, which leads to a more spatially uniform fluorescent emission and expected beam profile from an Nd:YAG laser equipped with a Spectralon reflector. As with any close-coupled cavity design, care has to be taken when choosing the rod-to-lamp spacing in order to optimise the trade-off between laser energy and beam quality.*

Lasing Efficiency: GPC vs. SPC & KPC

The slope efficiency (laser energy out as a function of lamp energy in) was determined for all three types of cavity. BSR reported that on average, the GPC with race-track geometry was 7% more efficient than the SPC, 15% more efficient than the KPC, and 40% more efficient than the GPC with circular cross section.

By employing a samarium-doped, UV-absorbing filter between the lamp and rod in the GPC cavity, BSL found that the slope efficiency of the laser increased slightly. The filter serves two functions: first, less UV radiation gets into the Nd:YAG rod and reduces losses that arise from thermal strain-induced birefringence; second, the samarium exhibits an absorption peak at 1064nm (the lasing wavelength of Nd:YAG) and therefore prevents, transverse, parasitic oscillations from occurring within the laser pumping chamber that can detract from the required laser output at high pump powers (so-called ‘roll-off’).

Conclusion: *the GPC (Spectralon) cavity exhibited significantly higher slope efficiency than any of the competing cavity designs, although the choice of close coupled geometry is important in determining the trade-off between energy and beam uniformity. A samarium-doped UV filter employed within the cavity increases the cavity efficiency and reduces the roll-off in cavity efficiency at the highest pump powers.*

Reliability: Spectralon

BSR conducted a life test on the Spectralon material by exposing it to over a million shots from the flashlamp at an average pump power of 225 watts (15 joules at 15Hz pulse repetition frequency). No degradation was observed. They went on to comment on previous tests that they had conducted that showed the need for clean coolant in the laser cavity, particularly with high average power or high pulse energy pump (flashlamp) sources. Critical is the need to avoid the use of plasticizers in the materials chosen for the laser cooling system, and the use of charcoal filters and deionizer resin cartridges is strongly recommended. In system where the coolant quality cannot be maintained, BSR recommends the use of a glass tube to seal the Spectralon behind (analogous to the glass tubes used with $BaSO_4$ reflectors).

Conclusion: *Spectralon is stable at lower average pump powers and energies (<225W at 15Hz) but at higher loads, the laser coolant must be maintained to a very high degree of purity to avoid contamination of the reflector and consequent reduction in laser output.*

Beam Divergence and Spatial Profiles: GPC vs. SPC & KPC

In general, it would be expected that as the pump energy rises, so the divergence of the laser beam would increase as a result of stronger rod lensing at higher average pump powers. BSL measurements supported this. They did find that the use of a UV-absorbing filter in the GPC, between the rod and flashlamp, had the effect of reducing the divergence by between 6 – 10%, but without compromising the laser efficiency.

BSL judged that the spatial beam profiles for the diffusely reflecting cavities were, qualitatively, very similar, but superior to that from the SPC. In the specular cavity, lasing occurred most strongly along the long axis of the Nd:YAG rod which leads to a greater variation in peak intensity across the laser beam, about 25% higher (ratio of peak to average) than for a diffuse cavity. This will be of concern where damage to sensitive optical components must be avoided. BSL also reported that the output energy and peak intensity fluctuated more from the SPC than from a diffuse cavity.

Conclusion: *Spectralon cavities impart improved uniformity onto the output of an Nd:YAG laser, with specular cavities suffering from 25% higher variations in peak intensity with a correspondingly higher risk of damage to optical components. Spectralon also imparts reduced pulse to pulse variations compared with specular reflectors. The use of a UV-absorbing filter within the Spectralon cavity minimises the divergence from a flashlamp pumped Nd:YAG laser.*

Summary Advantages of Spectralon as a Laser Cavity Reflector

Specification	Feature	Benefit
Diffuse reflectance (as opposed to specular)	Reduced hot spots in output (25% lower variation peak-to-mean versus specular reflector)	1. Lower risk of damage to optics
		2. Beam more predictable
		3. Improved output stability
	Reduced risk of parasitic oscillations	4. Lower risk of damage to laser optics
		5. Reduced roll-off (drop off in output at maximum pump levels)
Near-Lambertian diffuse reflectance	More uniform pumping of laser medium	6. Spatial profile more uniform
		7. Reduced non-symmetric aberrations (coma & astigmatism)
>99% reflectance 400-1000nm (up to 19% higher than competing materials)	Higher reflectance in absorption bands of the laser leading to improved slope efficiency	8. Higher laser output power/energy (e.g. 30% higher for lamp pumped, Q-switched Nd:YAG laser)
Inert, stable to >300°C, UV resistant	Maintains long-term reflectance, no tarnishing	9. Laser output remains more stable, long term