LASER MATERIALS CORPORATION

VCT AG

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ND:YAG

Nd:YAG Material Properties

Chemical/Physical

Chemical Formula	$Y_{2.97}Nd_{0.03}Al_5O_{12}$
Formula Weight	595.3 g·mole^{-1}
Crystal System/Structure	Cubic/Garnet
Space Group	O_h^{10}-Ia3d
Lattice Constant	12.01 Å
Melting Point	1950 ±20 °C
Density	4.55 g·cm^{-3}
Hardness (Knoop)	1350 ±35 kg·mm^{-2}

Mechanical

Modulus of Elasticity (E)	310 GPa (45 x 10^6 psi)
Poisson's Ratio (ν)	0.3
Tensile Strength (σ_t)	175-200 MPa (25-30 x 10^3 psi)

Thermal

Specific Heat Capacity (C_p)	0.59 J·g^{-1}·K^{-1}
Thermal Conductivity (k)	0.13 W·cm^{-1}·K^{-1}
Thermal Expansion Coef. (α)	7 x 10^{-6} K^{-1}
Thermal Shock Parameter (R)	7-8 W·cm^{-1}

From the Thermal Shock Parameter, the fracture limit for thermal dissipation in a CW laser rod can be calculated:

For rods it is independent of rod diameter (= 8 R)	175-200 W·cm^{-1}
For slabs it is dependent on the aspect ratio (= 12R·W/t). For a 4:1 aspect ratio (=48R)	330-390 W·cm^{-1}

Note: These values are absolute maxima and can be greatly affected by surface finish, fixturing, etc.

Optical

Refractive Index (n)	1.818 at 1.064 µm
Temperature Coef. (dn/dT)	9.05 x 10^{-6} K^{-1}
Wavelength Dependence:	
0.80 µm	1.8245
0.90 µm	1.8222
1.00 µm	1.8197
1.10 µm	1.8170
1.20 µm	1.8152
Elastooptic Coefficients:	
P_{11}	-0.029
P_{12}	0.0091
P_{44}	-0.0615

Laser/Spectroscopic

Lasing System	Four Level
Lasing Upper State	$^4F_{3/2}$
Fluorescent Lifetime	230 µs
Main Pump Bands	0.75 & 0.81 µm

$^4F_{3/2} \rightarrow {}^4I_{11/2}$ Stark Level Transitions:

Transition	Wavelength (µm)	Relative Laser Performance
$R_2 \rightarrow Y_1$	1.05205	46
$R_1 \rightarrow Y_1$	1.06152	92
$R_2 \rightarrow Y_3$	1.06414	100 (Principle)
$R_1 \rightarrow Y_2$	1.0646	50
$R_1 \rightarrow Y_3$	1.0738	65
$R_1 \rightarrow Y_4$	1.0780	34
$R_2 \rightarrow Y_5$	1.1054	9
$R_2 \rightarrow Y_6$	1.1121	49
$R_1 \rightarrow Y_5$	1.1159	46
$R_1 \rightarrow Y_6$	1.12267	40

$^4F_{3/2} \rightarrow {}^4I_{13/2}$ Stark Level Transitions:

Transition	Wavelength (µm)	Relative Laser Performance
$R_2 \rightarrow X_1$	1.3188	34
$R_2 \rightarrow X_2$	1.3200	9
$R_1 \rightarrow X_1$	1.3338	13
$R_1 \rightarrow X_2$	1.3350	15
$R_2 \rightarrow X_3$	1.3382	24
$R_2 \rightarrow X_4$	1.3410	9
$R_1 \rightarrow X_4$	1.3564	14
$R_2 \rightarrow X_6$	1.4140	1
$R_1 \rightarrow X_7$	1.4440	0.2

Unless otherwise noted, data is for 1% Nd (atomic) at 300K. For more information, consult the following references from which the above data was compiled.

Walter Koechner, *Solid-State Laser Engineering-Third Completely Revised and Updated Edition* (Springer-Verlag, Berlin, Heidelberg 1992)

Alexander A. Kaminskii, *Laser Crystals-Their Physics and Properties, Second Edition* (Springer-Verlag, Berlin, Heidelberg, 1990)

CRC Handbook of Laser Science and Technology, Volume V, Optical Materials, Part 3: Applications, Coatings, and Fabrication, Marvin J. Weber Ed. (CRC Press, Boca Raton, FL 1987)

Information about our Nd:YAG laser crystal products

- Laser Rod Specifications
- Ordering Information

Information about Nd:YAG & crystal growth

- Nd:YAG Production at LMC
- Notes about Nd Concentration
- Properties of Nd:YAG

LASER MATERIALS CORPORATION

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Nd:YAG Production

Laser Materials Corporation produces Nd:YAG boules, and fabricates laser rods and slabs. Our crystal growth facility in Vancouver, Washington exclusively produces large diameter boules (currently, Ø82 mm) in lengths up to 250 mm while retaining acceptable Neodymium concentration levels. As a crystal grower, we concentrate on developing and improving the crystal growth process to produce high yields and consistently high material quality. Pure raw materials, precise formulation, and exacting growth control are the keystones of our operations.

¯75 x 208 mm boule section
(Nd:YAG, 1.1 at % Nd concentration)

Better than 99.997% pure yttrium and aluminum oxides, and 99.99% pure neodymium oxide are used.

99.999% pure or better shield gases are used throughout the crystal growth process.

All raw materials are stored and prepared in a clean environment.

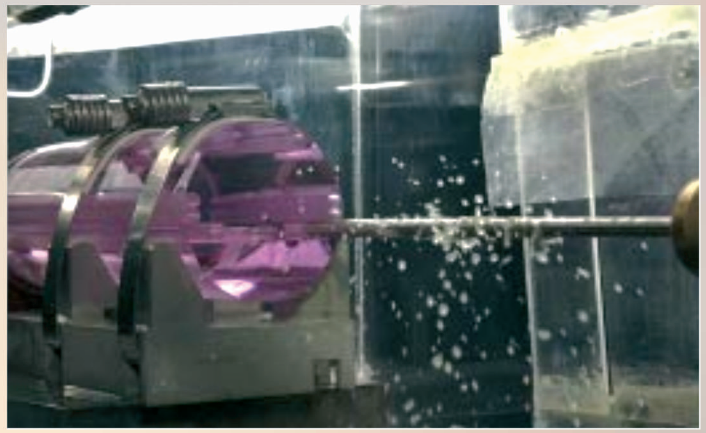
Constituent powders are thoroughly dried in high temperature ovens to reduce hydroxyl impurities.

The dried raw materials are carefully weighed on precision balances to insure precise stoichiometry and dopant concentration.

Computer control of the growth process and associated facilities produces the stable conditions required for consistent boule growth; cooling water and room air temperatures are maintained to within closely controlled tolerances.

Crystal growth control is based on weight gain for the most consistent boule diameter possible.

Laser rod "blanks" are extracted from completed boules using a diamond core drill; for slabs, a slicing saw is used to cut out the rough rectangular shape. In either case, the rough finished blanks are then sent out for the finishing operations of precision grinding to final size, polishing, and anti-reflection coating. You have the option of purchasing finished rods directly from us or purchasing unfinished "blanks" and using the fabricator of your choice.



Nd:YAG Crystal Growth

Growth of neodymium doped yttrium aluminum garnet (Nd:YAG) crystals by the Czochralski technique is the method of choice for virtually all commercially available Nd:YAG. This is a time consuming process requiring careful control of the growth environment over a period of 4 to 5 weeks just to produce one crystal boule. Still, the Czochralski method has proven to be the only acceptable way to produce Nd:YAG with sufficient optical clarity and homogeneity for use in a laser system.

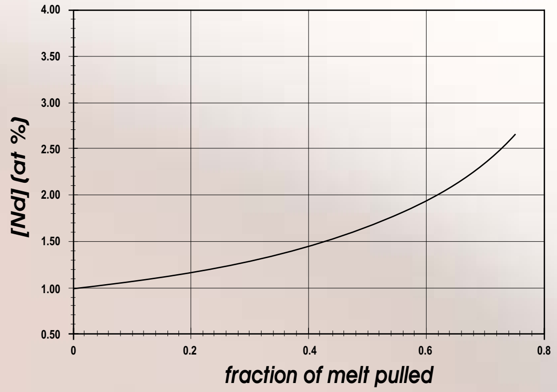
Crystal quality Vs. Boule size

One of the most important advances in Nd:YAG production in recent years has been the trend toward larger diameter boules. Internal strain in the grown boule is the principle cause of optical distortion in finished laser rods more than a few tens of millimeters in length (in shorter rods, the quality of the end finish is more important). Larger boules have significantly lower strain levels over much of their cross section resulting in significantly lower optical distortion in finished rods.

An additional advantage of larger boules is reduced cost. The cross-sectional area is increased while the linear growth rate remains comparable, resulting in an increased rate of material growth. At large diameters, Nd:YAG is more sensitive to process parameter fluctuations and obtaining high yields of good product is more difficult. But as a result of improved control electronics and computerization of the growth process, growth rate fluctuations can be maintained well within tolerance to provide high yields of good product at large diameter.

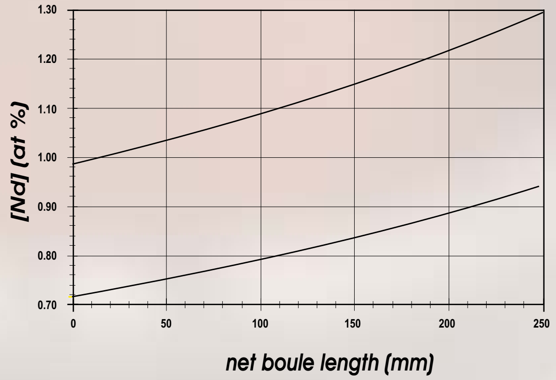
Neodymium Concentration

In neodymium doped yttrium aluminum garnet, neodymium substitutes for yttrium in the crystal lattice. However, because neodymium is larger than yttrium, this substitution does not occur readily. In fact, the concentration of neodymium in the crystal is only a small fraction of its concentration in the melt. Since the growing crystal is continually rejecting neodymium the concentration of the melt (and hence the crystal) increases as the growth progresses. To minimize this effect it is necessary to use a large crucible and to pull only a small fraction (typically 20-30%) of the total material available. The upper graph shows how the concentration of neodymium increases as a function of melt fraction pulled.



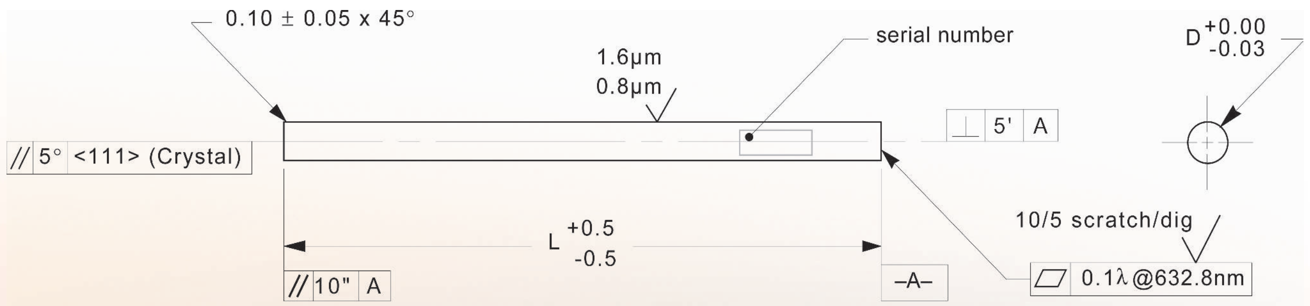
At Laser Materials Corporation, we grow boules at three average Nd concentrations: 0.60% Nd, 0.8 ND and 1.10% Nd. The Nd conc. profile for each is illustrated in the lower graph. The composition is engineered to provide the specified average concentration in 200 mm lengths. Lengths up to 250 mm can be provided with slightly higher average Nd concentrations.

For material less than 200 mm, the average concentration will vary depending on from where in the boule the material is cut. Each individual laser rod we ship is supplied with data including the average Nd concentration and the change in concentration over the rod's length. Standard tolerances for various rod lengths are listed on our laser rod specification sheet.



It should be noted that the absolute accuracy of the neodymium concentration must take into account how accurately the distribution coefficient (ratio of dopant concentration in the crystal to that in the melt) is known. At Laser Materials Corporation our formulations are based on a value of 0.18, which is consistent with industry practice and most determinations in the literature.

Nd:YAG Laser Rods

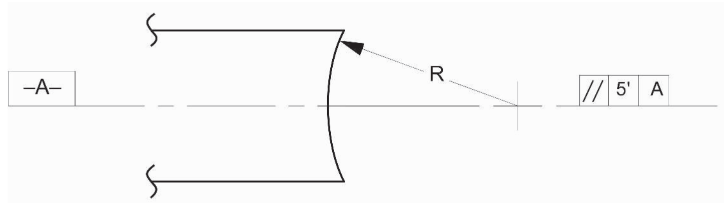


L mm	D mm	Standard Grade Extinc. Ratio (dB)	Standard Grade Wave. Error (λ)	Premium Grade Extinc. Ratio (dB)	Premium Grade Wave. Error (λ)	Standard [Nd]=1.1 Atom% Tolerance of Average [Nd]	Standard [Nd]=1.1 Atom% Δ[Nd] Over Rod Length	Low [Nd]=0.8 Atom% Tolerance of Average [Nd]	Low [Nd]=0.8 Atom% Δ[Nd] Over Rod Length
50	3		<.19		<.13				
50	4	>25	<.21	>30	<.15	±.08	0.06	±.07	0.05
50	5		<.24		<.16				
65	3		<.20		<.14				
60	4	>24	<.22	>29	<.15	±.08	0.08	±.07	0.06
65	5		<.26		<.17				
75	3		<.21		<.15				
75	4		<.24		<.17				
75	5	>23	<.28	>28	<.18	±.08	0.10	±.07	0.07
75	6		<.31		<.20				
75	6.35		<.32		<.21				
75	8		<.38		<.24				
100	4		<.28		<.18				
100	5		<.32		<.21				
100	6	>22	<.36	>27	<.23	±.08	0.13	±.06	0.09
100	6.35		<.37		<.24				
100	8		<.44		<.28				
125	5		<.36		<.23				
125	6		<.41		<.26				
125	6.35	>21	<.43	>26	<.27	±.07	0.16	±.05	0.11
125	8		<.51		<.31				
125	9.53		<.59		<.36				
150	6.35		<.48		<.30				
150	8	>20	<.58	>25	<.35	±.05	0.18	±.04	0.13
150	9.53		<.67		<.40				
200	8		<.71		<.42				
200	9.53	>19	<.82	>24	<.49	±.02	0.23	±.02	0.17
200	10		<.86		<.51				
250	8		<.84		<.50				
250	9.53	>18	<.98	>23	<.57	±.03	0.31	±.03	0.22
250	10		<1.03		<.60				

Coatings

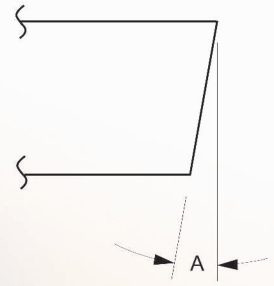
Type	Reflectivity %R per Surface	Damage Threshold (20nS Pulse, GW·cm⁻²)	Damage Threshold (CW, kW·cm⁻²)
AR @1064nm	<0.15	>1.4	>25
HR @1064nm	>99.9	>1.0	>25
Partially Reflecting	95 to 99 ± 0.5	>1.0	>25
Partially Reflecting	90 to 95 ± 1	>1.0	>25
Partially Reflecting	10 to 90 ± 3	>1.0	>25

Ordering Information



Radiused End

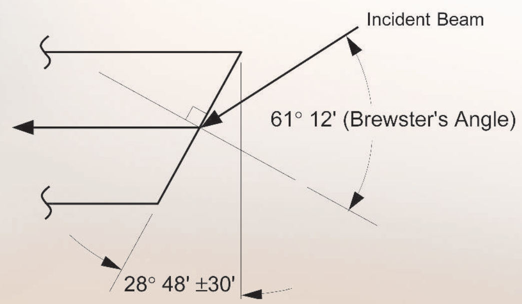
R (m)
0.5±.05
1.0±.1
2.0±.2
3.0±.3
5.0±.5
10±1



Wedged End

A
30' ± 10'
1° ± 10'
2° ± 10'
6° ± 10'
8° ± 10'

Note: if both ends wedged parallel, A-B angle < 10"



Brewster End

% Reflectivity = .06% for plane polarized incident beam at limit of angle tolerance.

Part Numbering

[Atom % Nd]NY[P] – [Diameter (mm)] – [Length (mm)] – [A-End/B-End] – [A-Coating/B-Coating]

0.80% --- 08
1.10% --- 11

Premium --- P
Standard --- Blank

Note: Indicate anti-parallel wedged ends by a negative angle on one end

Flat -------- F
Radiused -- R+Radius
Wedged --- W+Angle
Brewster -- B
Special ---- S
Unfinished N

Anti Reflection ------ A
High Reflection ------ H
Partial Reflection ---- P(%R)
None ------------------ N

Example:
08NY-6.35-100-W1/W1-A/A
Designates 0.08% standard grade Nd:YAG , D=6.35mm L=100 mm, both ends angled 1° parallel, and an AR coating on both ends.

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