KIGRE, INC.

QX LASER GLASSES

These phosphate glass laser materials exhibit a chemical durability that is comparable to silicate glasses. QX glasses are designed to withstand high thermal loading and shock

PROPERTIES	QX/Nd	QX/Er	QX/Yb
Laser Wavelength Peak (nm)	1054	1535	1032
Emission Cross Section ($x10^{-20}cm^2$)	3.8	0.8	0.4
Absorption Cross Section ($x10^{-20}cm^2$)	0.7	1.7@977nm	1.4
Fluorescence Lifetime (us)	353	7900	2000
Fluorescence Linewidth (nm) FWHM	27.6	55.0	56.5
Index of Refraction (n_D)	1.538	1.532	1.535
(n_F)	1.543		
(n_C)	1.536		
(n_F) - (n_C) ($x10^{-5}$)	815	848	834
Abbe Number	66.0	63.7	61.1
Index of Refraction (laser line) .	1.53	1.521	1.52
dn/dt (20-40 ^oC.) ($x10^{-7}/^oC$.)	- 4	-21	-21
Thermo-stress Birefr. Coeff. Q=[E/2(1-µ)] (C_1-C_2) ($x10^{-7}/^oC$)	9.0	9.1	9.1
Thermo-optical Coeff. W=[dn/dt+ (n-1)] ($x10^{-7}/^oC$) @ 70^oC	59	41	41
Thermo-optical Coeff. W=[dn/dt+ (n-1)] ($x10^{-7}/^oC$) @ 30^oC	51	33	33
Transformation Temperature (^oC)	506	470	450
Deformation Temperature (^oC)	535	502	485
Coeff. of Thermal Expansion (20-40^oC) ($x10^{-7}/^oC$).	72	76	83
(20-100 ^oC)	84	88	95
(20-300 ^oC)		99	
Nonlinear Index n2 ($x10^{-13}$ esu)	1.17	1.22	1.22
Density (g/cc)	2.66	2.93	2.81
Thermal Conductivity (W/mK)	0.85	0.85	0.85
Young's Modulus ($x10^{+3}N/mm^2$)	71	67	67
Poisson's Ratio	0.24	0.24	0.24
Stress Optical Coeff. B=[C_1-C_2] ($x10^{-6}$ mm^2/N)	2.1	2.3	2.3
Stress Thermal-Optical Coeff. "P" ($x10^{-6}$/K) P = dn/dt - (E/2(1-µ)] (C_1+$3C_2$)	-3.6	5.1	5.1
Knoop Hardness (kgf/mm^2)	503	435	435
Durability (Wt. loss $x10^{-5}$ g/cm^2, H2O,100^oC, 1Hr) ED2, Q-246, = 5.5 x $10^{-5}g.cm^2$	5.0	5.2	5.2
Thermal Loading Limit, TLL (watts/inch) (unstrengthened)	> 300	> 150	> 300
LAMP PUMPED (strengthened)...5x80mm rod	> 900	> 450	> 900
LAMP PUMPED (strengthened)...10x150mm rod	> 500	> 250	> 500

conditions in both ion-exchanged strengthened and un-strengthened configurations.

Note: TLL = Rupture Strength. Unstrengthened QX glasses exhibit a Rupture Strength of ~ 10,000 psi. Strengthened QX glasses exhibit a Rupture Strength of ~ 40,000 psi.. The TTL is strongly dependent upon rod barrel surface conditions.

Wt% to ions/cc: Wt%(g)/100g x 2.9g/cc x 2 Er^{3+}/382.52g/mole x 6.02 x 10^{23} ions/mole =ions/cc Er^{3+}

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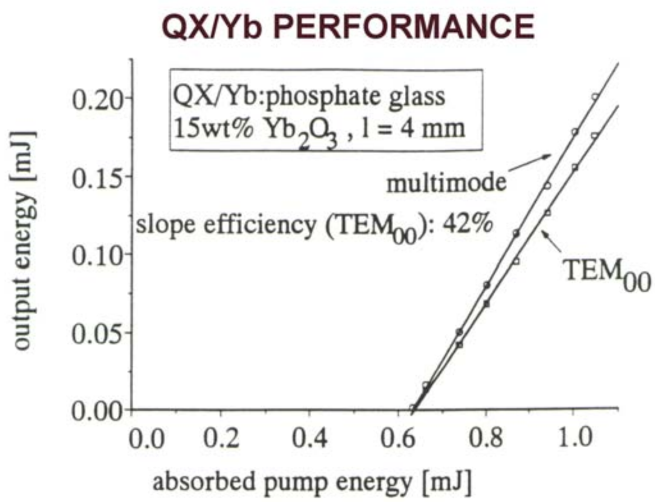
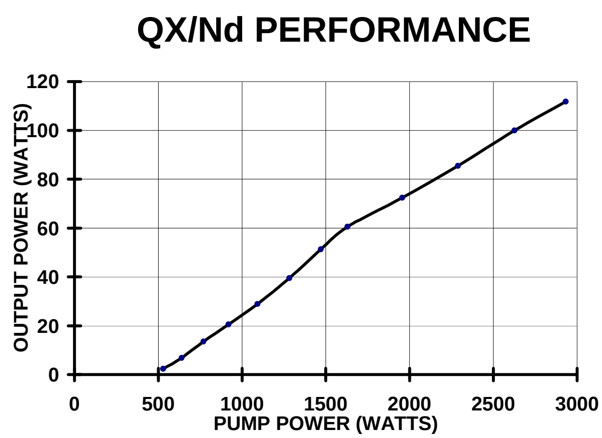
QX/Yb

Tunable 1025-1060nm output, 975nm pump



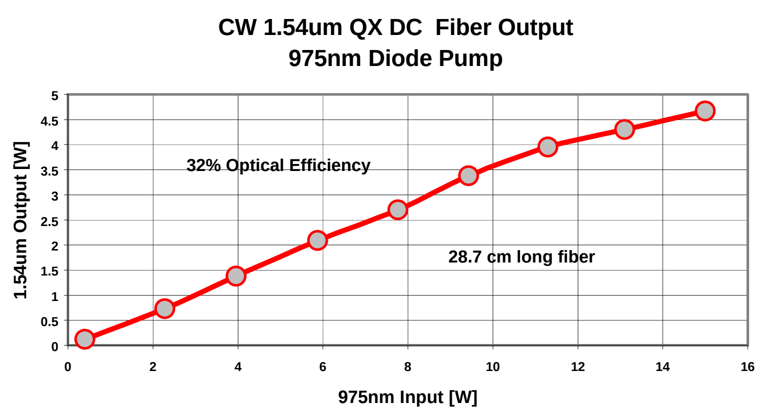
QX/Nd

Lamp pump 10mm x 6" rod, 60%R OC, 2ms PW, 5.4% Slope Efficiency



QX/Er

1.54um DC LMA Fiber Laser



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QX LASER GLASS

Thermal Strength Notes

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The thermal shock resistance T_{SH} is the temperature difference **(ΔT)** at which the fracture stress (commonly called the tensile yield stress) is reached and failure occurs. For isotropic materials this may be expressed in the relationship,

$$T_{SH} = \frac{\sigma_f (1-\mu)\kappa}{\alpha E}$$

where σ_f is the fracture stress, **μ, κ , E,** and α are the material's Poisson ratio, thermal conductivity, Young's modulus and linear coefficient of thermal expansion, respectively.[1]

Krupke examined the **$(1-\mu)\kappa / \alpha E$** portion of the term as a material figure-of merit (FOM).[2] He excluded the fracture stress as this is not a totally intrinsic property. The fracture stress depends on the physical condition of the surface of the material and is often difficult to obtain precise values. The Poission ratio, thermal conductivity, and Young's modulus do not change significantly with glass composition. Thus, the thermal shock resistance is heavily dependent upon the thermal expansion coefficient. In general the lower the thermal expansion coefficient, the higher the thermal shock resistance.

QX/Nd glass exhibits a thermal expansion coefficient of 83×10^{-7} / ^{o}C. (25-100^{o}C) This may be compared to 120×10^{-7} / ^{o}C for many common phosphate laser glasses. In addition to its superior thermal-mechanical properties, QX also demonstrates excellent thermal-optical properties. The thermal coefficient of optical path length, as expressed in terms of **$dn/dt+(n-1)\ \alpha$** , should be as low as possible in order to avoid excessive thermal lensing. Here, **dn/dt** is the temperature coefficient of refractive index, n is the refractive index at the lasing wavelength, and α is the thermal expansion coefficient. QX/Nd glass exhibits a low thermal coefficient of optical path length due to its negative temperature coefficient of refractive index and low thermal expansion coefficient. New QX/Er^{8080} and QX/Yb^{8080} base glasses have joined Kigre's Q-100, Q-98 and QE-7S laser glass materials in the "athermal" club.

ATHERMAL LASER GLASS PROPERTIES

The athermal properties of Kigre laser glass materials is determined by the following basic relationship:

$$\alpha \ (n-1) = -dn/dt$$

Where:

α = Thermal Expansion
n = Index of refraction @ 1.54um
dn/dT = The change in index with temperature

This relationship dictates a constant optical path length regardless of the laser rod temperature when utilized with external laser resonator mirrors. For athermal windows the idea is the same as for active laser materials. The coefficient of thermal expansion, refractive index and dn/dT are determined for the glass composition along with a set of coefficients relating these properties to the composition. These properties are then used to estimate TLC_{13} and TLC, the "thermal lensing coefficient", from the equations:

$$TLC_{13} = (n-1)(1+n)\ \alpha + dn/dT$$

$$TLC = TLC_{13} + (n_3\ \alpha\ E/4)(q_{11}+q_{12})$$

Where: α = Thermal Expansion
n = Index of refraction
dn/dT = The change in index with temperature
n_3 is Poisson's ratio
E is Young's modulus
q_{11} and q_{12} are the stress-optic coefficients

When a material is heated, the refractive index decreases due to a decrease in density. (This effect is the same for the different glasses.) At the same time, the bonds become weaker and the electrons become more loosely bound. This tends to increase the refractive index. This effect is different for the different glass formers and must be determined experimentally. Whether the material has a positive or negative dn/dT depends on the magnitude of these two components of dn/dT. At Kigre we provide customize and standard high optical quality glass materials to produce a thermal lensing balance and a distortion free laser beam optical path length.

QX based glasses are capable of being chemically strengthen via an ion exchange process. This process can increase rupture strength by a factor of 3 to 5 over the unstrengthened material. Comparable strengthened glasses have exhibited a modulus of rupture of greater than 50,000 psi. Consequently, QX's superior thermal lensing behavior, high laser cross-section, large energy storage capability, and high strength make this a choice material as a solid-state laser medium.

[1] W.D. Kingery et al., Introduction to Ceramics (Wiley, New York, 1975) pp. 823.
[2] W.F. Krupke, Insulator Materials in High Power Lasers for Inertial Fusion: Present and Future, UCRL-89439 (1983)

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