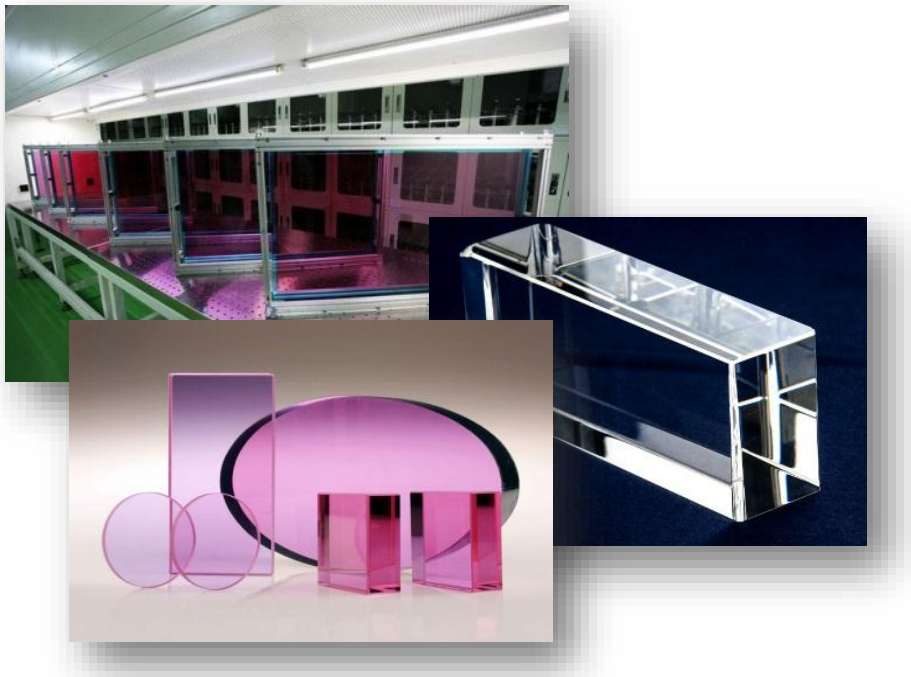
中国科学院上海光学精密机械研究所
Shanghai Institute of Optics and Fine Mechanics
Chinese Academy of Sciences

LASERGLASS

Research progress of laser glass in SIOM



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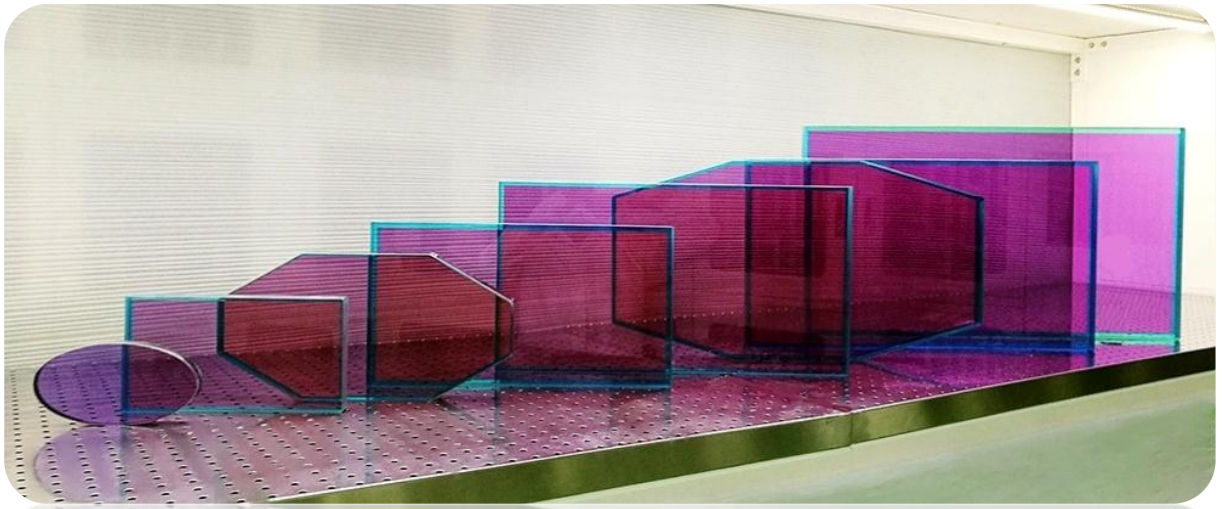
Outlines

- ◆N31 laser glass and application
- ◆N41 laser glass and continuous melting
- ◆Newly developed laser glasses
- ◆Conclusion

N31 laser glass

- **Phosphate glass has been used as laser glass matrix due to high concentration of rare-earth ions, low concentration quenching and high solubility of Pt^{2+} ions .**
- **N31 is kind of Nd doped phosphate laser glass developed by SIOM**
- **The N31 glass is developed in mid of 1990s. The composition research was finished at 1995, and its melting and cladding techniques for mass production get matured in recent years.**



Laser glass development in China

Main properties of N31, LG-770 and LHG-8 glasses

properties	N31(SIOM)	LG-770(Schott)	LHG-8 (Hoya)
σ （$10^{-20}cm^2$）	3.8	3.9	3.6
Nd^{3+} ion concentration （$10^{20}cm^{-3}$）	3.4	4.2	
Fluorescent lifetime （μsec）	310	320	
Radiative lifetime τ_{rad}(μsec)	351	350	351
Lasing wavelength λ_L(nm)	1053	1052.7	1053
Effective linewidth $\Delta\lambda_{eff}$(nm)	25.5	25.4	26.5
Density (g/cm^3)	2.87	2.585	2.83
n_d	1.540	1.5086	1.5296
n_L	1.535	1.4996	1.5201
ν Number	65.6	68.4	66.5
Nonlinear refractive index $n_2(10^{-13}esu)$	1.18	1.02	1.12
Glass transition temperature （°C）	450	461	485
α （30-70°C） （$10^{-7}/K$）	107	116	
dn/dT （30-70°C） （$10^{-6}/K$）	-4.3	-4.7	-5.3
dS/dT （30-70°C） （$10^{-6}/K$）	1.4	1.1	0.6
α （30-300°C） （$10^{-7}/K$）	127	133.6	127
Weight loss in distilled water	26μg/cm^2hr (100°C)	40μg/cm^2day (50°C)	

Application of N31 laser glass

- **About 1500 pieces N31 glasses with different aperture are used in high power laser systems worldwide, including Shenguang series, SULF, LULI 2000 et al.**
- **we are the main supplier of laser glasses in Shen Guang facilities in China.**

Some of customers in China

Some of our foreign customers

Outlines

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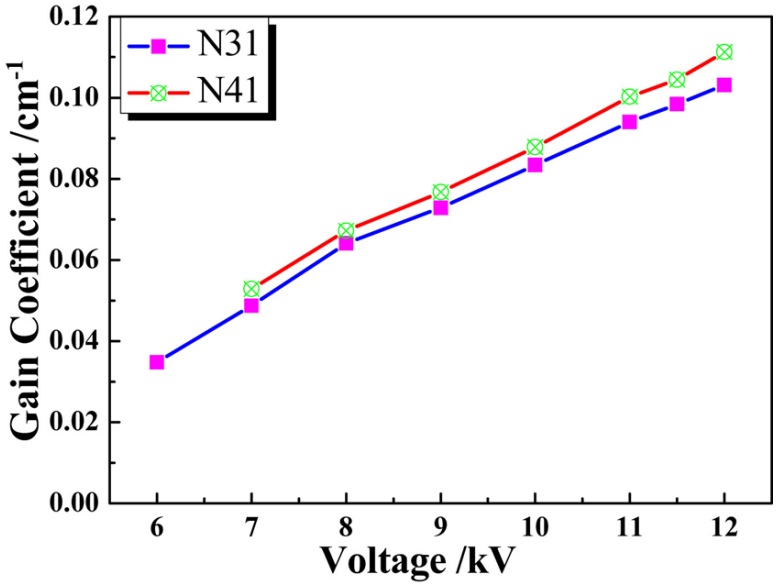
Main properties of N41, N31, LG-770 and LHG-8 glasses

properties	N41(SIOM)	N31(SIOM)	LG-770(Schott)	LHG-8 (Hoya)
σ （$10^{-20}cm^2$）	3.9	3.8	3.9	3.6
Nd^{3+} ion concentration （$10^{20}cm^{-3}$）	4.2	3.4	4.2	
Fluorescent lifetime （μsec）	310	310	320	
Radiative lifetime τ_{rad}(μsec)	355	351	350	351
Lasing wavelength λ_L(nm)	1053	1053	1052.7	1053
Effective linewidth $\Delta\lambda_{eff}$(nm)	25.0	25.5	25.4	26.5
Density (g/cm^3)	2.62	2.87	2.585	2.83
n_d	1.510	1.540	1.5086	1.5296
n_L	1.504	1.535	1.4996	1.5201
ν Number	68.4	65.6	68.4	66.5
Nonlinear refractive index $n_2(10^{-13}esu)$	1.04	1.18	1.02	1.12
Glass transition temperature （°C）	465	450	461	485
α （30-70°C） （$10^{-7}/K$）	121	107	116	
dn/dT （30-70°C） （$10^{-6}/K$）	-5.6	-4.3	-4.7	-5.3
dS/dT （30-70°C） （$10^{-6}/K$）	0.3	1.4	1.1	0.6
α （30-300°C） （$10^{-7}/K$）	140	127	133.6	127

Compared to N31 type glass, N41 has larger emission cross section and lower nonlinear refractive index

N41 laser glass



Gain coefficients of N31 and N41 glass rods with size of φ20mm×360mm

Nd^{3+} ions concentration：1.2×10^{20}ions/cm^3

Lifetime of N31：360μs

Lifetime of N41：370μs

Gain Coefficients of N31 and N41 laser glass slabs with Nd^{3+} content of 4.2×10^{20} ions/cm^3 have been measured. Under 16J/cm^3 xenon lamp pumping, the gain coefficients of of N31 and N41 laser glass are 5.0cm^{-1} and 5.3cm^{-1}.

N41 glass continuous melting

- Compare to N31 laser glass, N41 glass has larger thermal expansion coefficient, lower chemical stability and more likely to corrode refractory materials

- The continuous melting of N41 laser glass is more difficult than that of N31 glass:

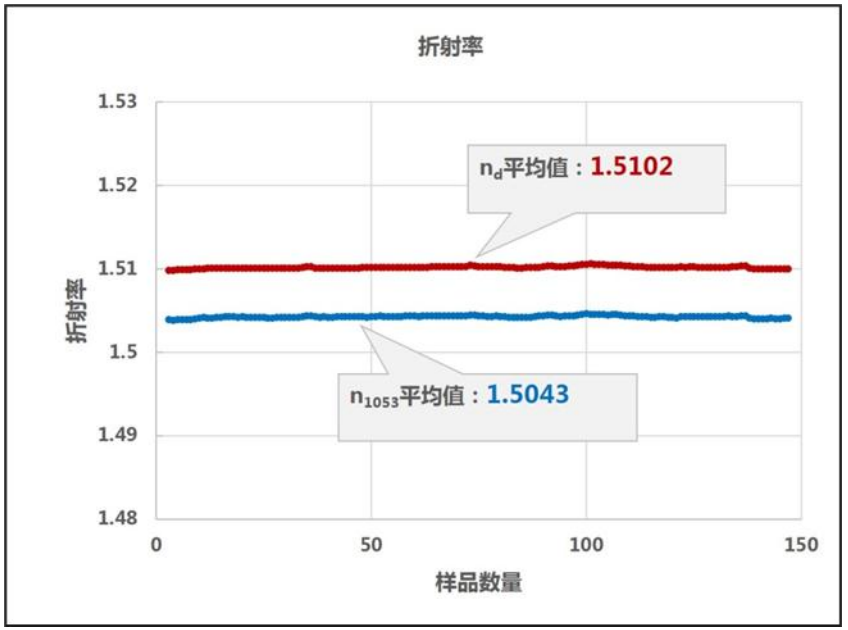
impurity control,
dynamics OH- removing,
crack control in annealing lehr

Finally, we have controlled the above 3 key techniques.

N41 glass continuous melting

laser glass continuous melting

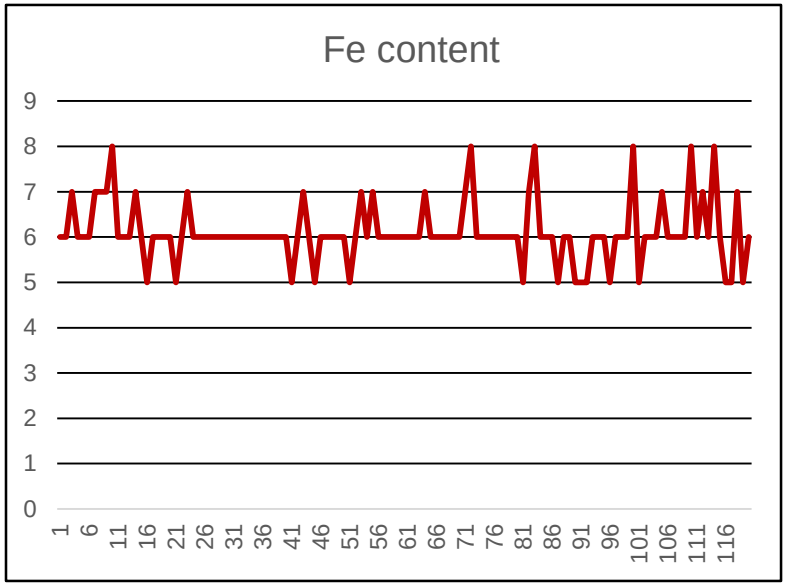
laser glass slabs



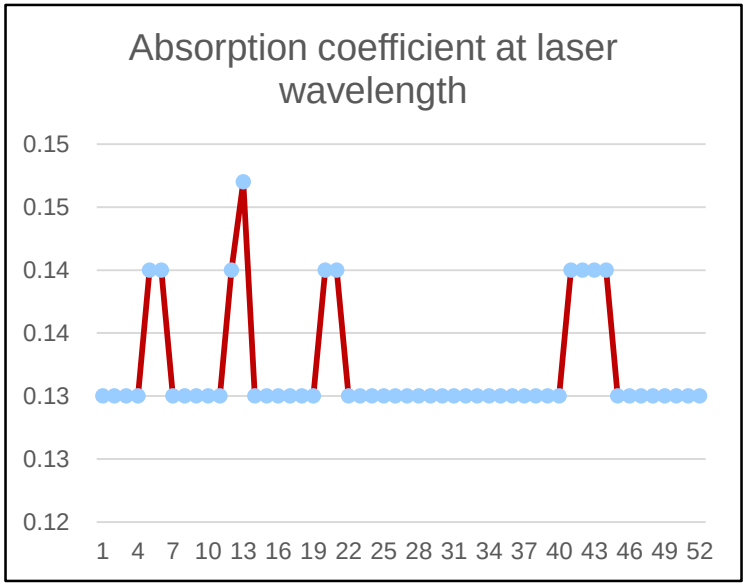
Average n_d: 1.5102, n_{1053}:1.5043

Refractive index of continuous melted N41 glass is very stable

N41 glass continuous melting



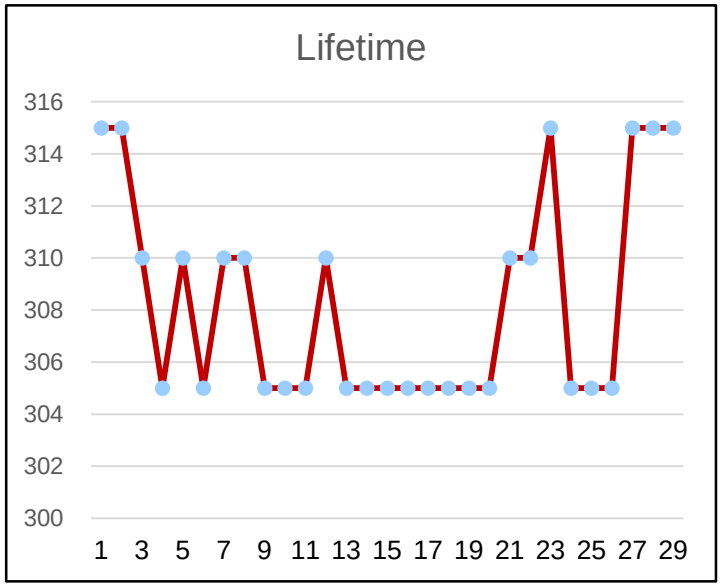
Average:6.5 ppm

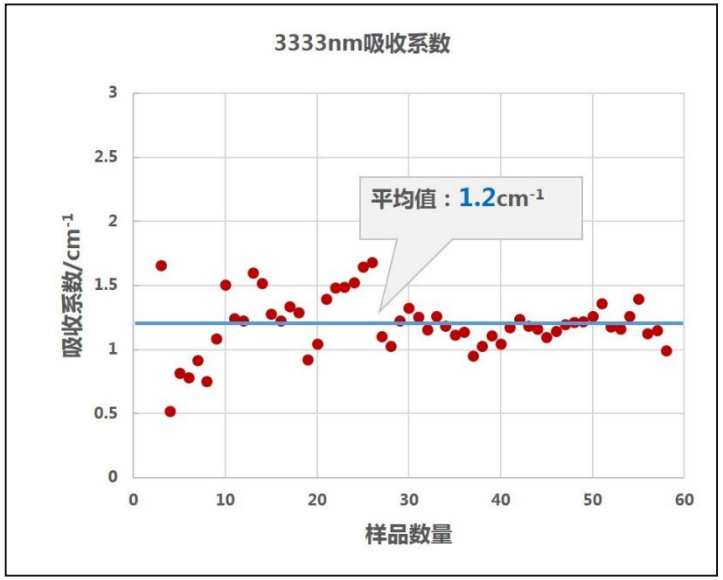


Average: 0.133% cm^{-1}

- **Fe is the main impurity of the refractory and induces absorption loss at laser wavelength**
- **The Fe content of continuous melted N41 laser glass is 6.5ppm and the average loss at wavelength is 0.133% cm^{-1}**

N41 glass continuous melting





Average: 310μs

Average: 1.2 cm^{-1}

- **Hydroxyl is an impurity in glass, which will reduce the fluorescence lifetime of laser glass**
- **The hydroxyl absorption coefficient of the continuous melted N41 laser glass is 1.2 cm^{-1} and the average lifetime is 310μs**

Outlines

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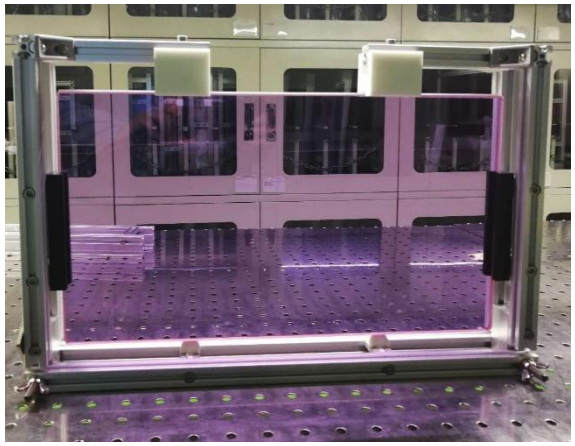
N51 laser glass

Main properties of different laser glasses

玻璃性能	N3142	N4142	N51	LG760
Nd concentration （$10^{20}cm^{-1}$）	4.2	4.2	4.0	4.0
Emission cross section （$10^{20}cm^{2}$）	3.8	3.9	> 4.3	4.5
Measured lifetime （μs）	≥300	≥310	≥320	285
Nonlinear refractive index （$10^{-13}esu$）	<1.20	<1.04	<1.04	1.02
Tg （°C）	445	467	405	350
Thermal expansion coefficient （20~300°C）	129	141	152	150
Weight loss (H_2O 98ºC)(mg/(cm^2*day))	0.12	0.41	2.2	

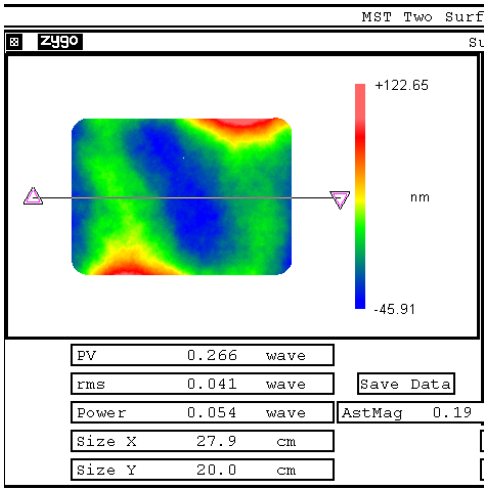
- **N51 is a newly developed of laser glass, properties of this kind of glass is similar to LG760 from Schott.**
- **The emission cross section is much higher than N31 and N41 type laser glass**
- **The nonlinear refractive index is much lower than N31 type laser glass**

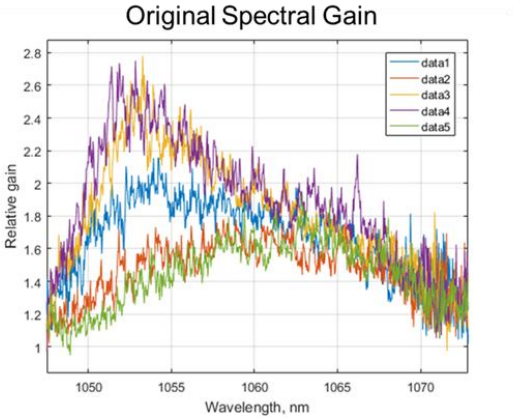
N51 laser glass

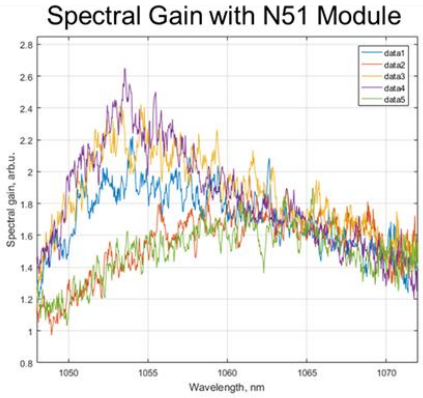


245mm×420mm×10mm

N51 type laser glass with size of 245mm×420mm×10mm has been polished and the corresponding PV and RMS values are 0.266 wave and 0.041 wave

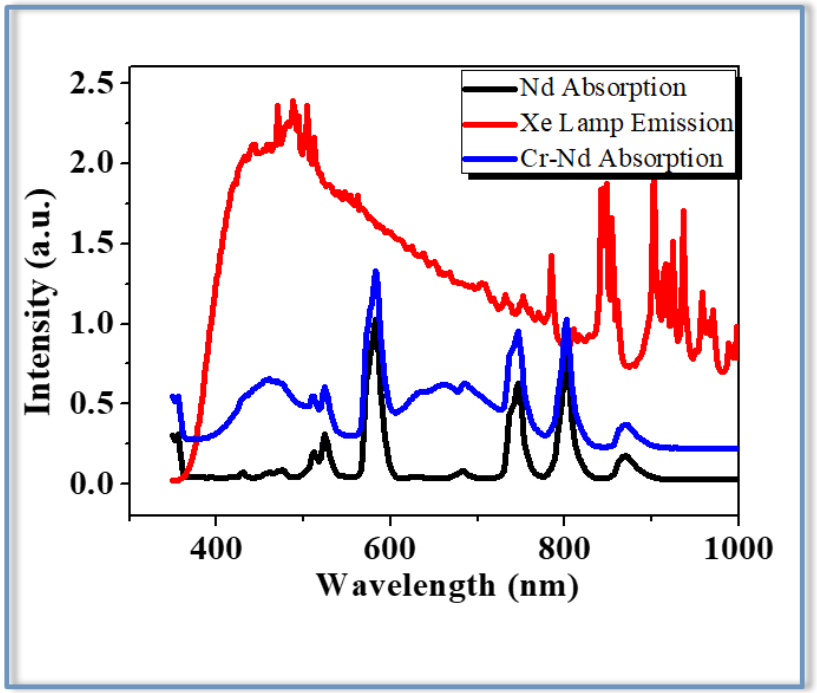




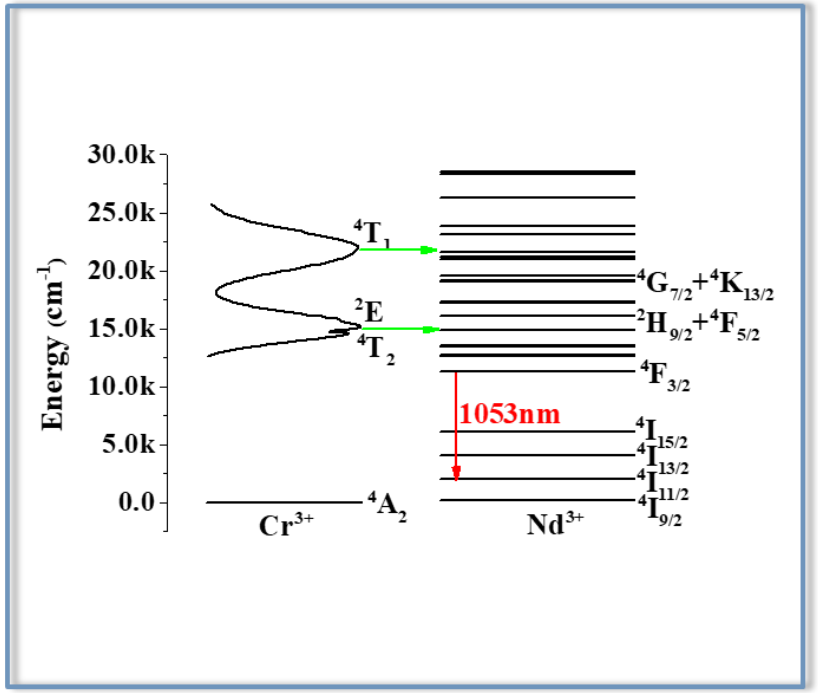


- **Gain properties have been measured by National Energetics Inc., the gain properties is similar to LG 760**
- **We also have calculated the gain coefficient of N51 under 16J/cm^3 pumping. It is 5.7cm^{-1}, and is much larger than N31(5.0cm^{-1}) and N41(5.3cm^{-1}).**

Cr-Nd codoped laser glass



Nd:glass absorption spectrum and Xe lamp emissiom



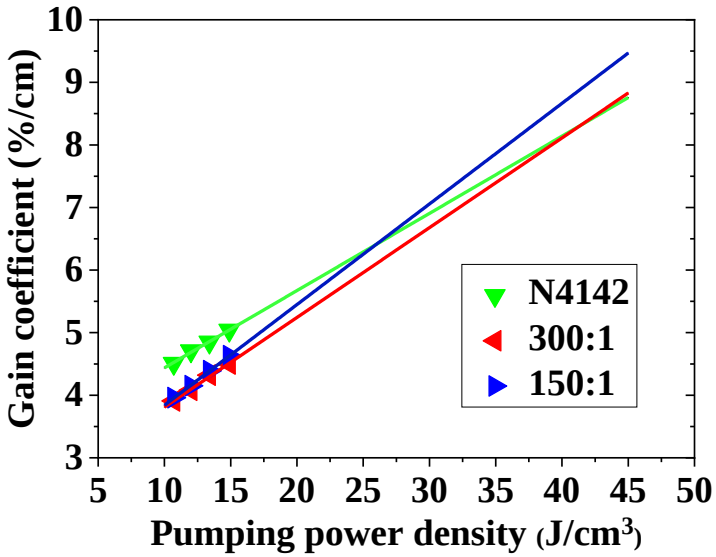
Energy transfer process

- **Cr^{3+} ion can enhance the Nd:phosphate glass absorption in visible wavelength band**
- **There is effective energy transfer process from Cr^{3+} to Nd^{3+}**

Cr-Nd codoped laser glass

Gain properties of Cr-Nd codoped laser glass rods (φ16×210mm，Nd_2O_3 1.2wt%）

Pumping energy	G			g		
	Nd doped	Cr-Nd codoped	$G_{Cr\text{-}Nd}/G_{Nd}$	Nd doped	Cr-Nd codoped	$g_{Cr\text{-}Nd}/g_{Nd}$
600J	2.61	2.86	1.10	0.046 cm^{-1}	0.050cm^{-1}	1.10
1176J	4.88	5.48	1.12	0.076 cm^{-1}	0.081 cm^{-1}	1.07
1600J	6.71	7.70	1.15	0.090 cm^{-1}	0.097 cm^{-1}	1.07

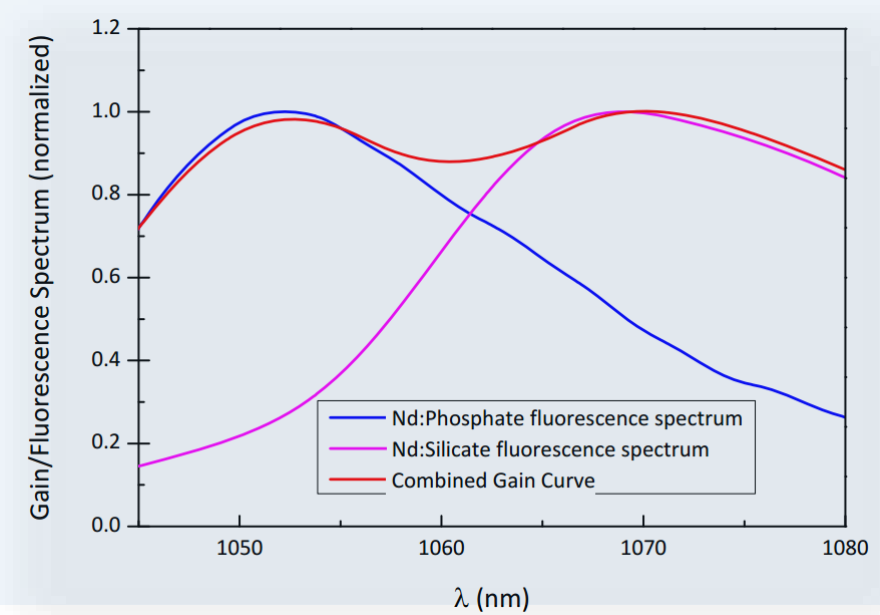


Gain properties of Cr-Nd codoped laser glasses. (Nd_2O_3 4.62wt%, $wt\%_{Nd2O3}/wt\%_{Cr2O3}=\infty$, 300, 150）

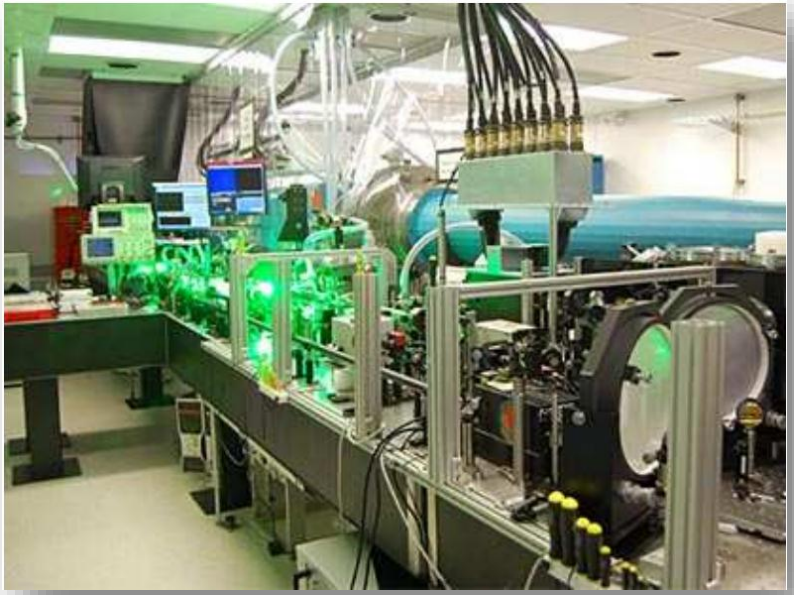
- **Compared with the non-Cr-doped neodymium glass, gain coefficient of Cr/Nd codoped glass increases faster as the pump power density increases;**
- **As the content of Cr_2O_3 increases, the gain coefficient of the codoped glass increases faster as the pump power density increases**

Broadband aluminate laser glass

- **Mixed laser glass： Two or more neodymium glasses of different matrices are used in the amplifier to obtain a broad gain bandwidth**
- **Texas Petawatt Laser: using mixed glass amplifier, they have obtained a 1.26 PW laser pulse**



Emission spectra of phosphate laser glass / silicate laser glass



Texas Petawatt Laser

Broadband aluminate laser glass

- New kind of laser glass with broadband emission and longer emission wavelength should be developed
- Nd doped Aluminate laser glass is suitable

Table 1. Optical Properties of Neodymium-Doped Laser Glasses[a]

Optical Properties	APG-1 Phosphate	Q-246 Silicate	K-824 Silicate	L-65 Aluminate
Peak-fluorescence wavelength (nm)	1053.9	1061	1064.5	1067
Line width (nm) FWHM	27.8	28.5	38.2	41.23
Peak stimulated emission cross section (cm^2)	3.4×10^{-20}	2.4×10^{-20}	2.4×10^{-20}	1.8×10^{-20}
Saturation fluence (J/cm^2) at peak emission wavelength	5.5	7.0	7.0	10.0
Calculated radiative lifetime (μs)	370	406	274	349
Refractive index at peak spectral emission	1.537	1.558	1.70327	1.6637
Nonlinear refractive index (esu)	1.13×10^{-13}	1.49×10^{-13a}	3.44×10^{-13a}	2.92×10^{-13a}

[a]Measured and calculated values listed from data sheets provided by Lawrence Livermore National Laboratories.

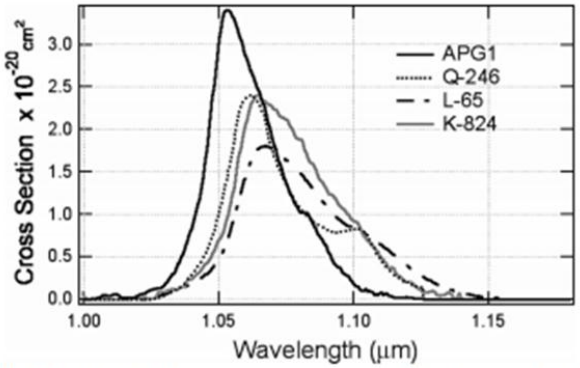
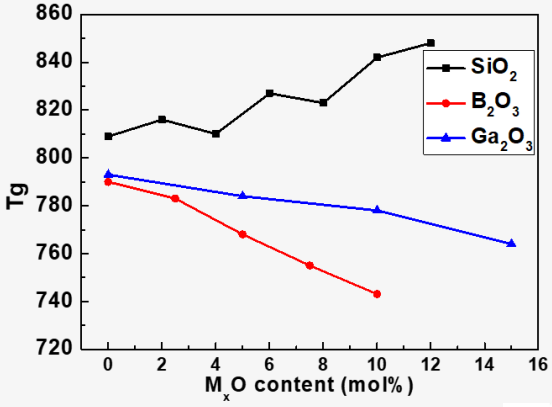


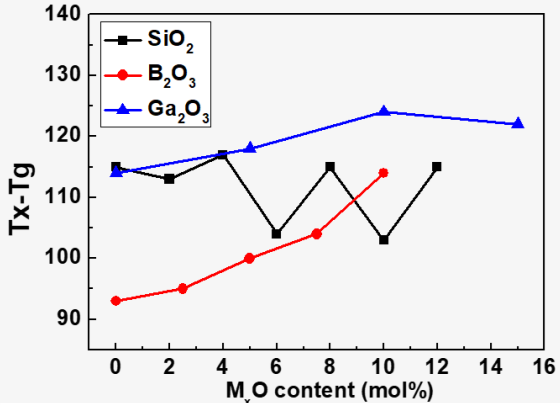
Fig. 1. Stimulated emission cross sections of neodymium-doped laser glasses.

Disadvantages:

- **High melting temperature**
- **Easily to crystallize**
- **It is very hard to obtain glass with high optical quality**

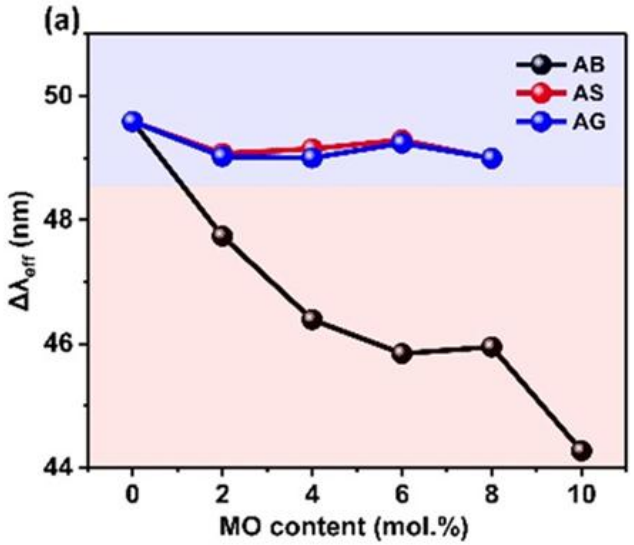
Broadband aluminate laser glass

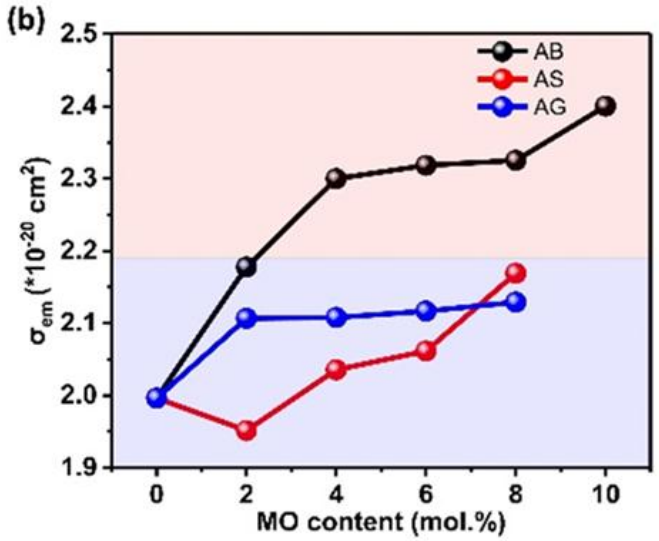




Introduce Ga_2O_3 and B_2O_3 into aluminate glass can decrease the melt temperature and improve thermal stability

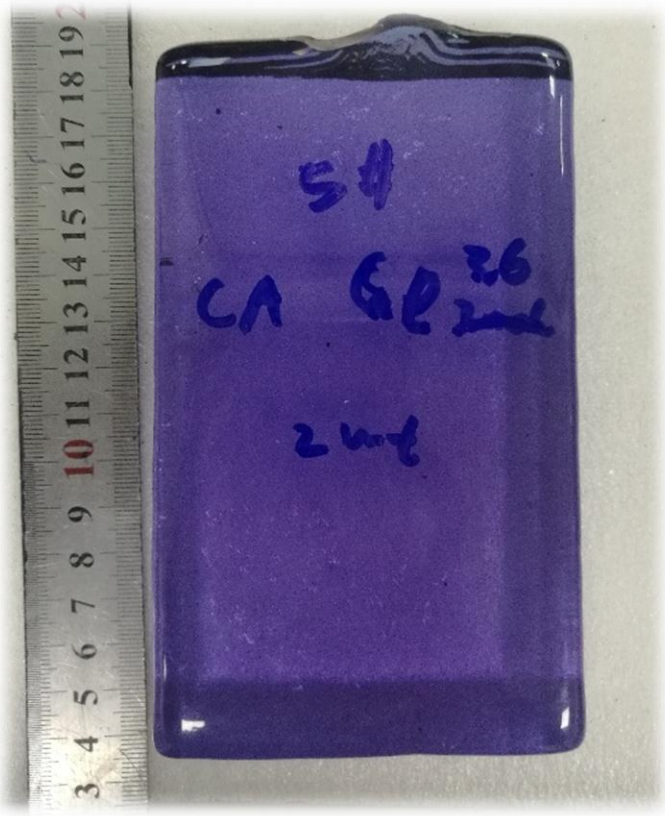
Introduce B_2O_3 into aluminate glass will decrease the emission bandwith





Introduce Ga_2O_3 into aluminate glass is an effective way to improve the thermal properties

Broadband aluminate laser glass



Properties of aluminate laser glasses developed by SIOM

Glass	CAG1	CAG2	CAG3
n_{1064}	1.6855	1.685	1.6851
ρ/gcm^{-3}	3.54	3.55	3.54
$C/10^{20}ion.cm^{-3}$	3.69	3.74	3.67
$\lambda(^4F_{3/2}$-$^4I_{11/2})$/nm	**1067**	**1067**	**1066**
FWMH/nm	**41.3**	**42**	**41.1**
$\Delta\lambda_{eff}$/nm	**49.5**	**49.8**	**49.2**
$\tau\ (^4F_{3/2})/\mu s$	210	201	196
$\sigma_e/10^{-20}cm^2$	1.87	1.85	1.88

Central emission wavelength of the developed aluminate laser glass is longer than 1065nm, and the effective emission bandwidth is lager than 49 nm

High repetition laser glass

Thermal shock resistance parameter

$$FOM_{tm} = \frac{\sigma_{\max} K (1-\nu)}{\alpha E},$$

$$\sigma_{\max} = \frac{K_{Ic}}{\sqrt{a}},$$

Thermal shock resistance parameters of different phosphate laser glass

Glass type	热导率K（$W*Mk^{-1}$）	断裂韧性Klc（$Mpa*m^{1/2}$）	杨氏模量E（GPa）	膨胀系数a（$10^{-6}K^{-1}$）	抗热振系数FOM（$W*m^{-1//2}$）
N31	0.560	0.48	56.4	11.5	0.31
P-Si0	0.979	1.03	85.3	7.87	1.13
P-Si4	0.975	1.13	81.4	7.73	1.32
P-Si8	0.973	1.13	81.1	7.61	1.34
P-Si12	0.950	1.13	78.1	7.39	1.40
P-Si16	0.935	1.04	77.5	7.37	1.27
P-Si20	0.920	1.01	73.2	6.96	1.36

High repetition laser glass

Properties of Nd:phosphate glasses for high average power glasses from different makers

Properties	Schott		Hoya	Kigre	SIOM	
	APG-1	APG-2	HAP-4	QX-Nd	NAP2	NAP4
Laser wavelength(nm)	1054	1054	1054	1054	1054	1052
Cross section ($10^{-20}cm^2$)	3.4	2.4	3.6	3.34	3.7	3.2
Radiative lifetime(us)	361	456	350	353	360	360
Refractive index,nd	1.537	1.513	1.5433	1.538	1.542	1.530
Temp. coeff. refractive index dn/dT (10^{-6}/K)	1.2	3.4	1.8	10	-0.87	1.9
Temp. coeff. Optical path dS/dT (10^{-6}/K)	5.2	6.0	5.7	4.8	3.6	5.0
Thermal expansion Coeff. α (10^{-7}/K)	76	51	72	72	96	71
Thermal conductivity (W/MK)	0.78	0.80	1.02	0.85	0.77	0.86
Density (g/cm^3)	2.63	2.56	2.70	2.66	2.76	2.60
Elastic modulus ($1000N/mm^2$)	70	64	68.8	71	58	67
Knoop Hardness (kgf/mm^2)	450	420	470	503	382	549
Thermal shock resistance ($W/m^{1/2}$)	0.70	1.02	1.28	-	1.0	1.3

Conclusions

- **N31 laser glass has been used in many high power laser glass facilities**
- **N41 laser glass with better gain property than N31 have been developed and manufactured using continuous melting technology**
- **Several new kinds of laser glass have developed for different laser applications**