



# Metal-oxides borate glasses doped with $\text{Nd}^{3+}$ for photonic applications

**Eakgapon Kaewnuam**

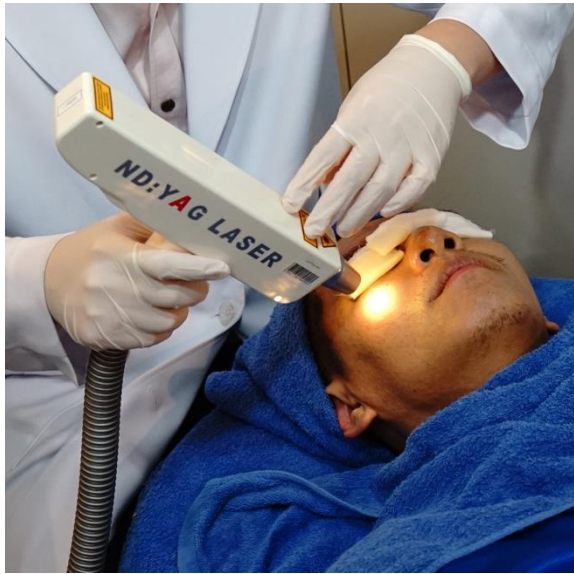
*Muban Chombueng Rajabhat University*

**Supakit Yonphan, Petch Borisut, Jakrapong Kaewkhao**

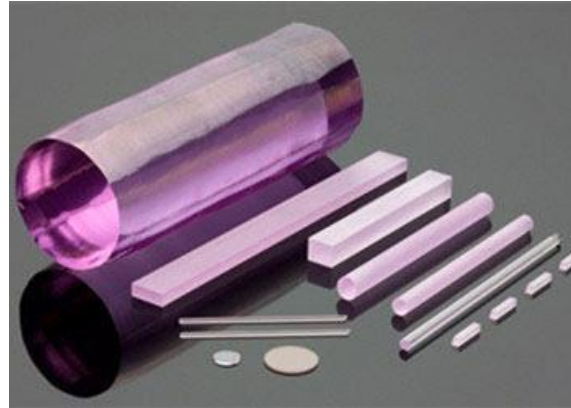
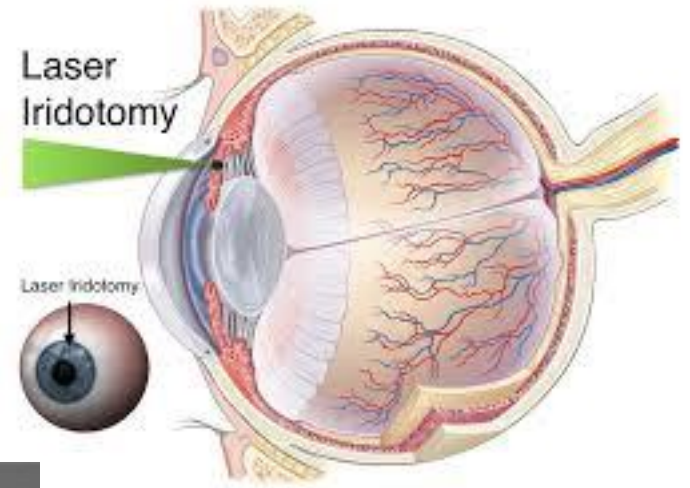
*Center of Excellence in Glass Technology and Materials Science (CEGM), Nakhon Pathom Rajabhat University*

**Pham Hong Minh**

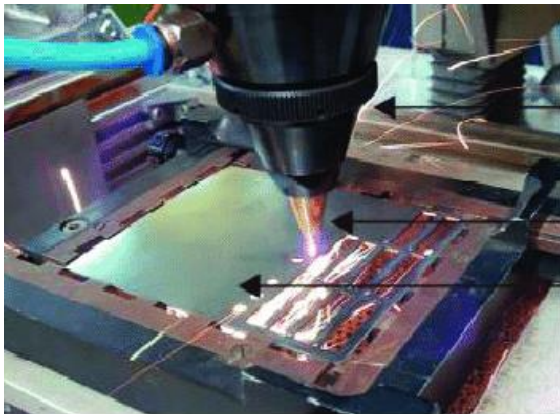
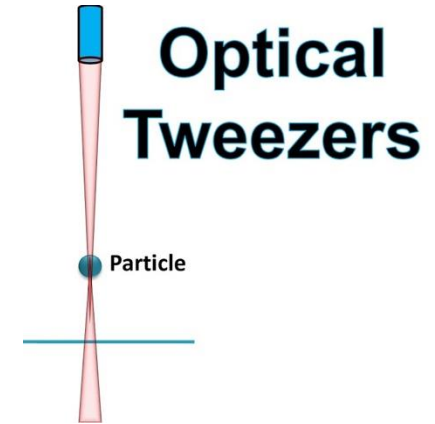
*Vietnam Academy of Science and Technology*



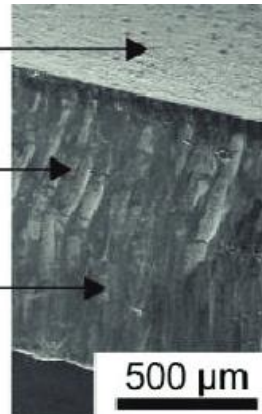
# Nd:YAG laser



# Nd:Y<sub>3</sub>Al<sub>5</sub>O<sub>12</sub>



surface  
laser head  
cut edge  
nozzle  
NiTi-sheet

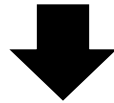


# Aluminium garnet compound family

$Y_3Al_5O_{12}$  (YAG) : 1960s



$Lu_3Al_5O_{12}$  (LuAG) : 1990s



Ion	Ionic radius (Å)
$Y^{3+}$	0.900
$Lu^{3+}$	0.977
$Gd^{3+}$	1.053
$Al^{3+}$	0.535
$Ga^{3+}$	0.620

$A_3(B,C)_5O_{12}$  : Until present

Possible A element = Y, Lu, Gd or mixing between them

Possible B & C element = Al, Ga or mixing between them

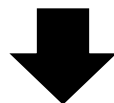
Multi-component garnet

# Aluminium garnet compound family

$Y_3Al_5O_{12}$  (YAG) : 1960s



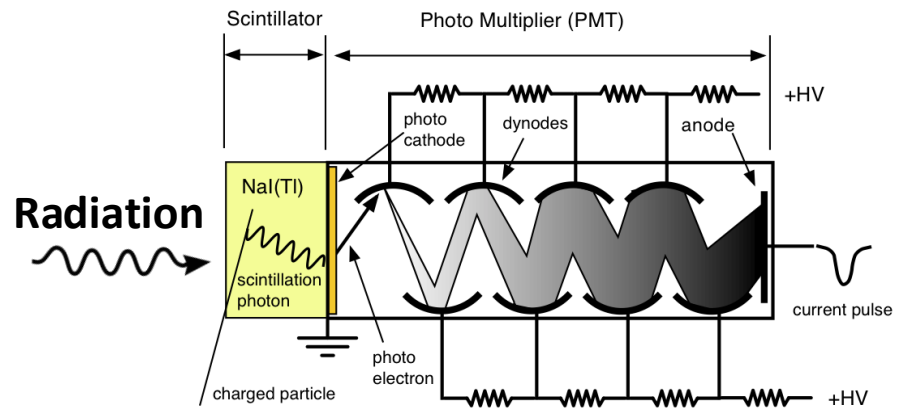
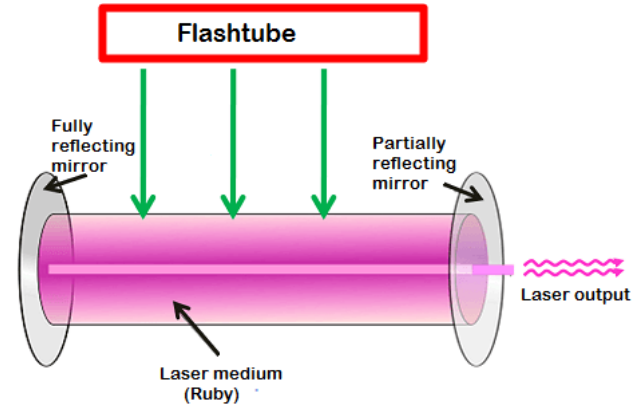
$Lu_3Al_5O_{12}$  (LuAG) : 1990s



$A_3(B,C)_5O_{12}$  : Until present

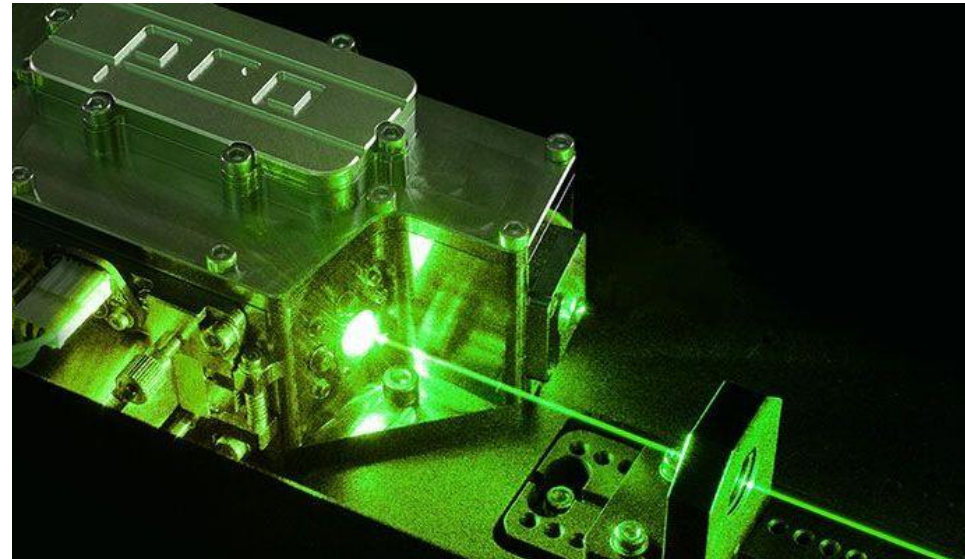
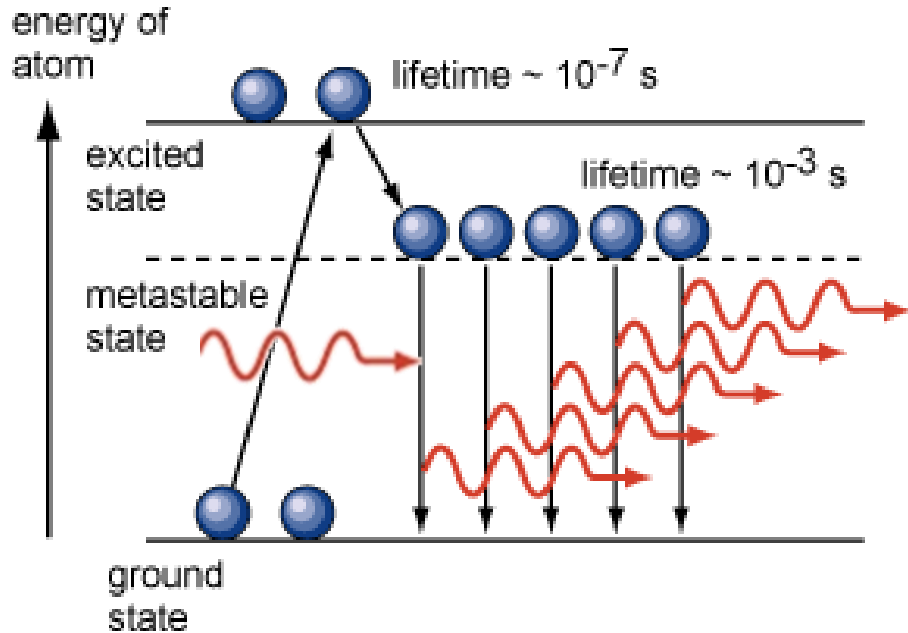
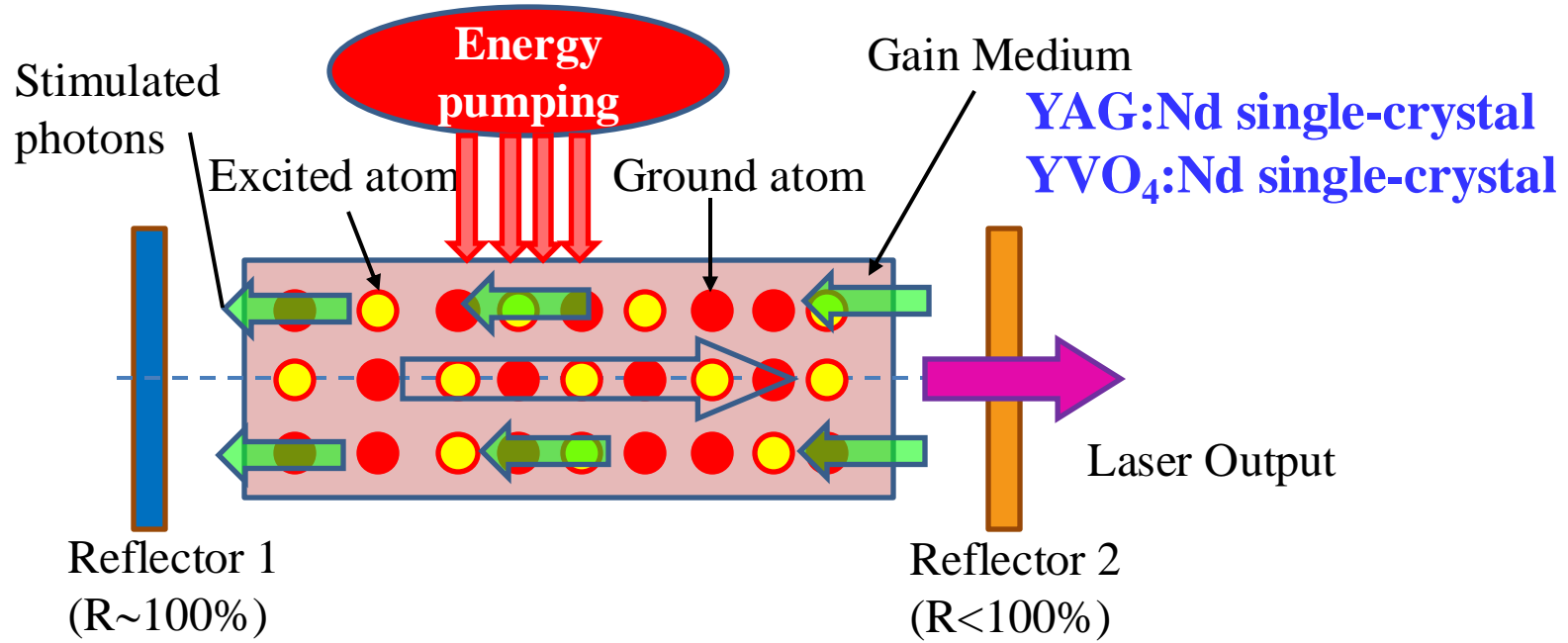
Possible A element = Y, Lu, Gd or mixing between them

Possible B & C element = Al, Ga or mixing between them

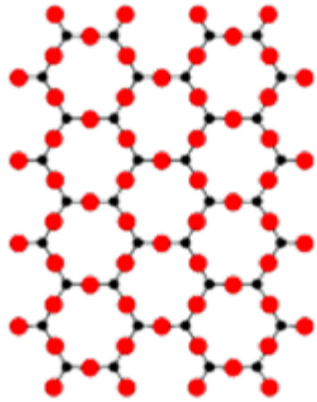


Doped with  $Nd^{3+}$  → Strong luminescence for laser / photonic

# Light Amplification by Stimulated Emission of Radiation

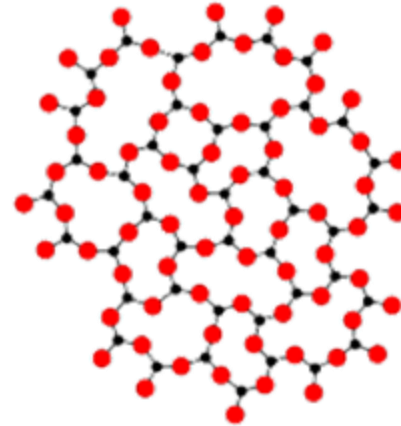


# Bulk material



Crystalline A<sub>2</sub>O<sub>3</sub>

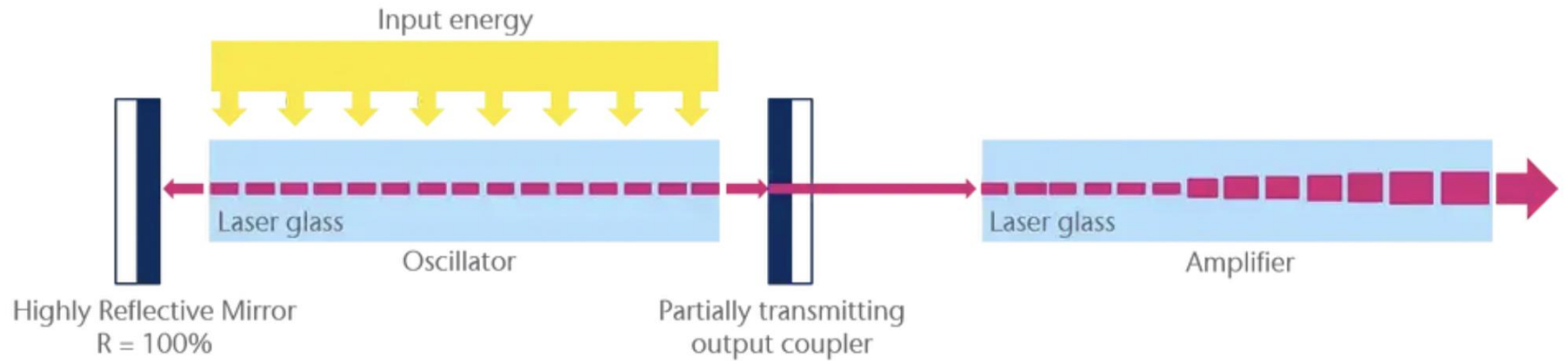
Convert  
→  
using base  
chemicals



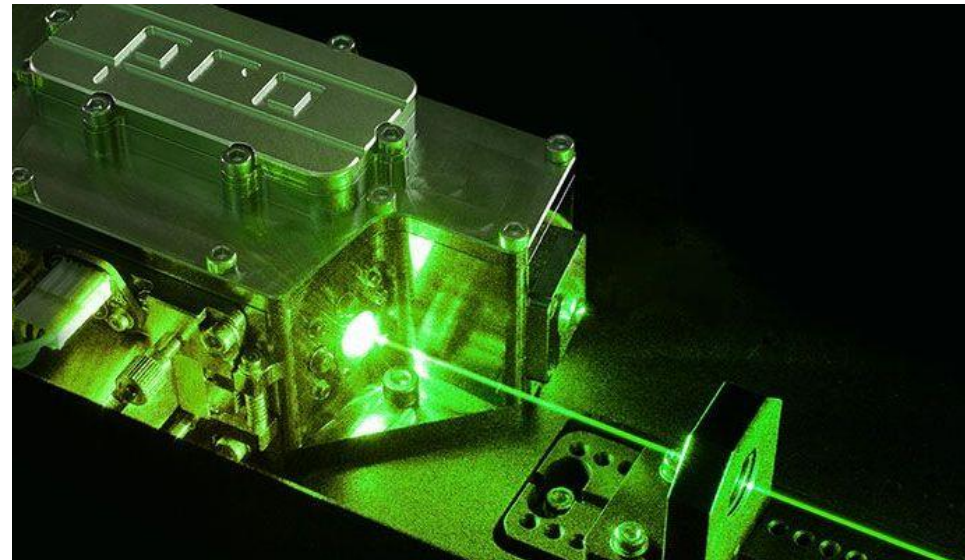
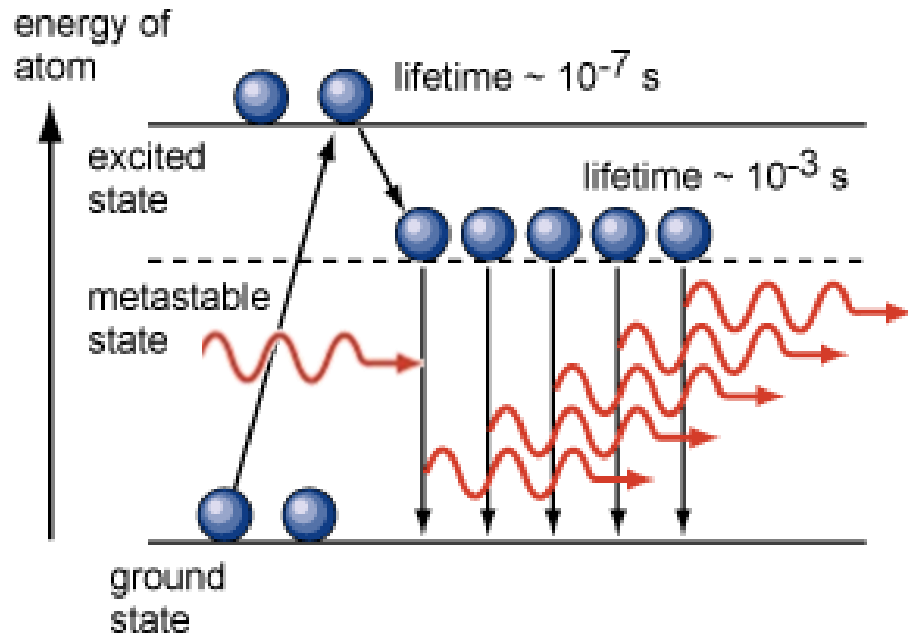
Glassy A<sub>2</sub>O<sub>3</sub>

Single-crystal	Glass
<b>Crystalline</b> structure	<b>Amorphous</b> structure
<b>Obvious</b> electronic bandgap	<b>Unclear</b> electronic bandgap
<b>Difficult</b> for preparation	<b>Easy</b> for preparation
Can prepare in <b>limited size</b> and <b>shape</b>	Can prepare in <b>various sizes</b> and <b>shapes</b> with same properties
Chemical ratio is strict and <b>fixed</b>	<b>Wide range</b> of chemical ratio
<b>High</b> production cost	<b>Low</b> production cost

# Light Amplification by Stimulated Emission of Radiation

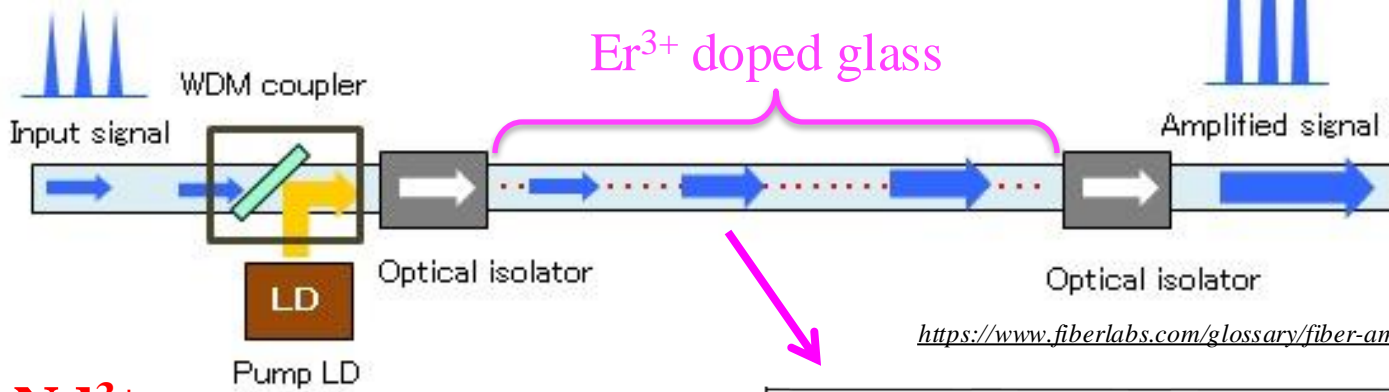


<https://www.schott.com/en-gb/solutions-magazine/edition-1-2022/from-light-to-laser>



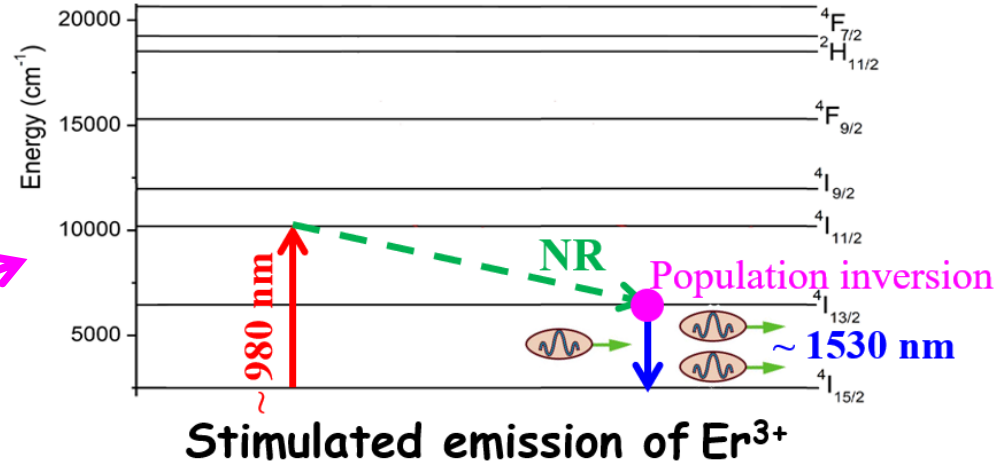
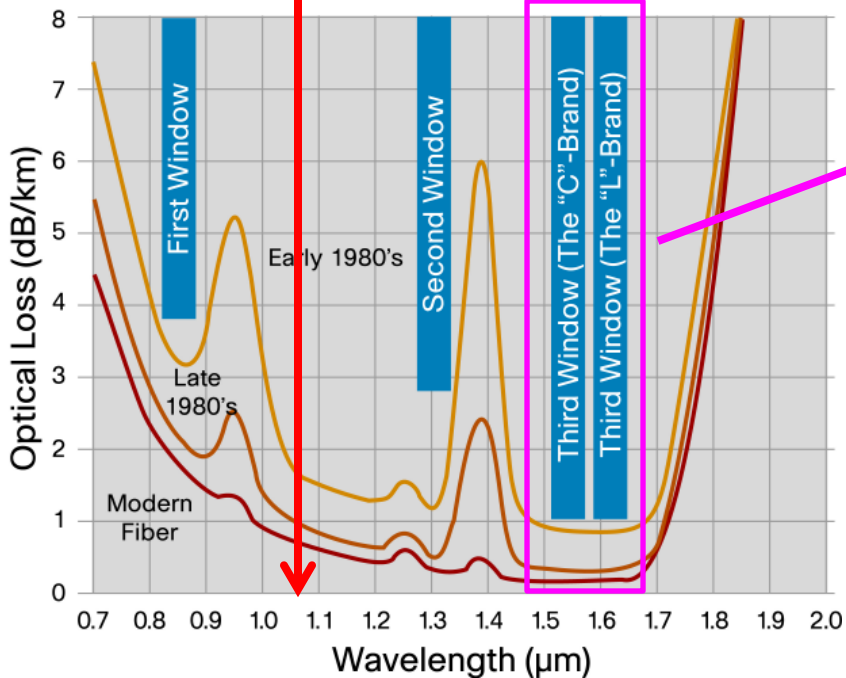
# Optical fiber / wave guide amplifier

How about  $\text{Nd}^{3+}$  doped glass ?



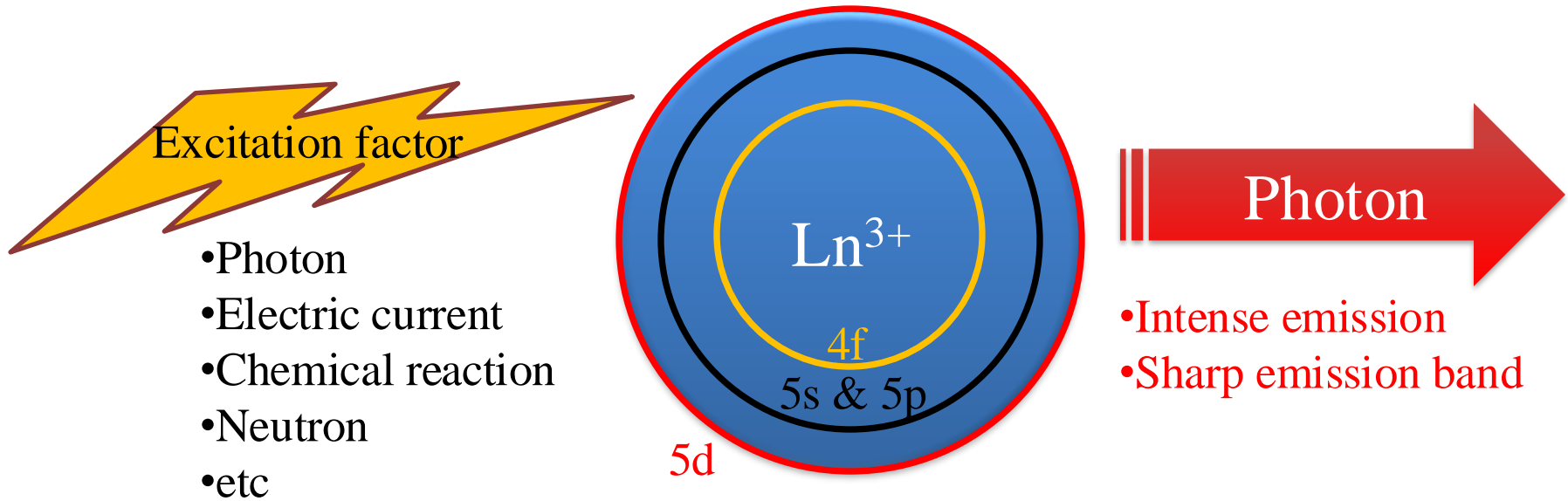
<https://www.fiberlabs.com/glossary/fiber-amplifier/>

$\text{Nd}^{3+}$





# Strong luminescence properties of Ln<sup>3+</sup>

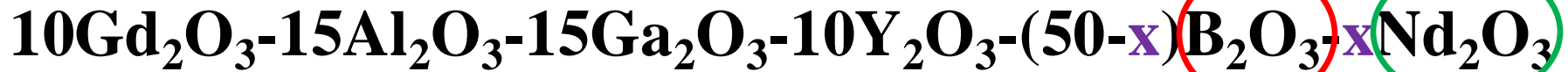


Ln <sup>3+</sup>	Emission	$\tau$
Sm <sup>3+</sup>	Red-Orange	ms
Dy <sup>3+</sup>	Yellow-Blue, White	ms
Eu <sup>3+</sup>	Red	ms
Nd <sup>3+</sup>	NIR, $\lambda/2$ to Green	$\mu$ s
Er <sup>3+</sup>	NIR, Up-conversion to Red	ms
Tb <sup>3+</sup>	Green	ms
Ce <sup>3+</sup>	Blue	ns

Intra 4f-4f transition  
*Forbidden, but stable,  
Support by asymmetric  
ligand*

Inter 4f-5d transition  
*Allowed, but easy to disturb*

# GaLuAlYB:Ce glass composition



Adapted metal oxide from  
multi-component garnet family

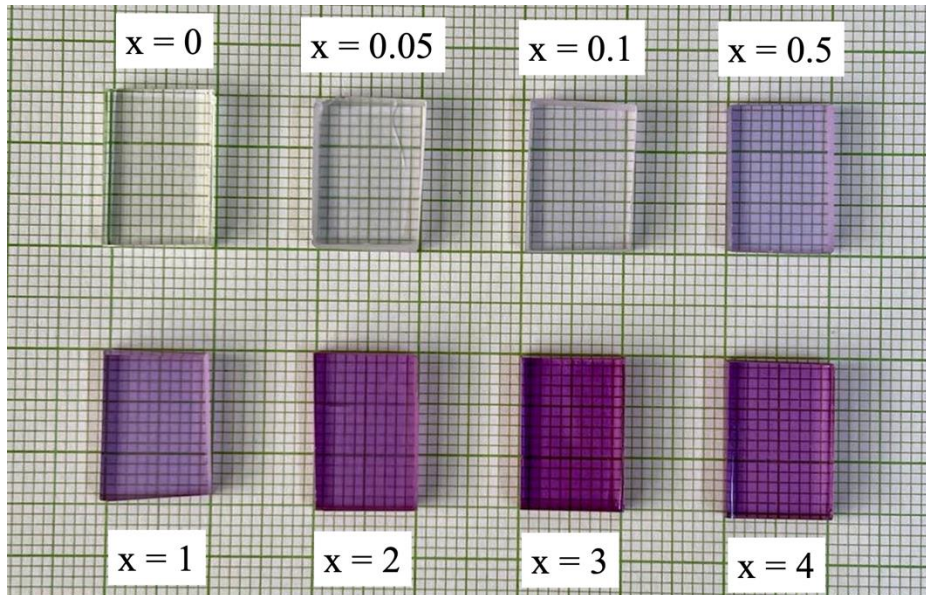
$x = 0, 0.05, 0.1, 0.5, 1, 2, 3, 4$  mol%

Excellent glass former

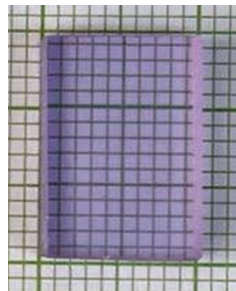
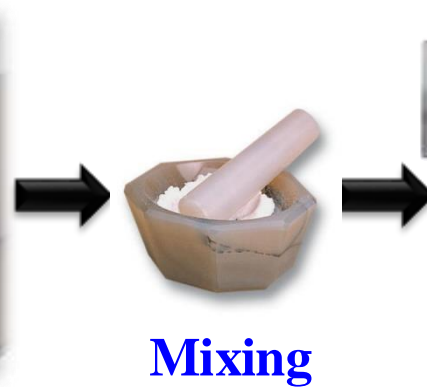
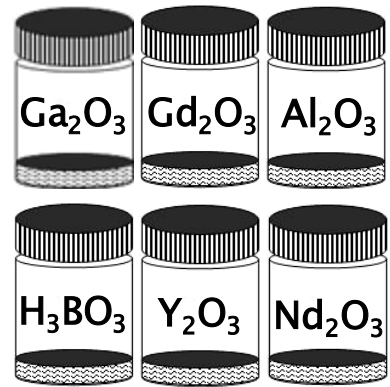
- High transparency
- High chemical durability
- Non-hygroscopic
- Easy to form network
- Good  $\text{Ln}^{3+}$  solubility

Strong NIR luminescence

- Popular in solid-state laser
- Can be converted to green laser
- Not fast decay time



# Glass preparation (melt - quenching)



# Characterization Instrument

Absorption spectra



UV-VIS-NIR Spectrophotometer  
(UV-3600, Shimadzu)

$\rho$ ; Archimedes principle



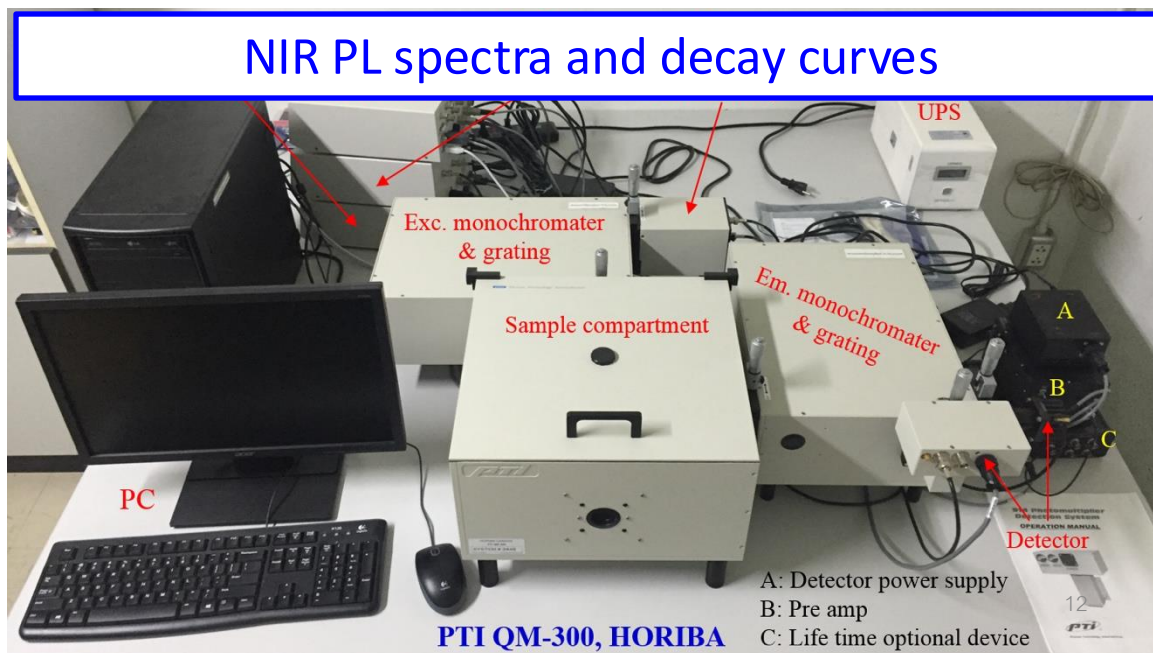
4-digit sensitive microbalance  
(Denver, Pb214)

Refractive index



Abbe refractometer  
(Atago, NAR-1T)

NIR PL spectra and decay curves



- A: Detector power supply
- B: Pre amp
- C: Life time optional device

Absorption spectrum

$$f_{exp} = 4.318 \times 10^9 \int \alpha(\nu) d\nu$$

$f_{exp}$

**Judd-Oflet analysis**

Least-square fitting

$\Omega_2, \Omega_4, \Omega_6$   
&  
 $f_{cal}$

$$f_{cal} = \frac{8\pi^2 m c \nu}{3 h e^2 (2J + 1)} \cdot \frac{(n^2 + 2)^2}{9n} S_{ed}$$

$$A_R = \frac{64\pi^4 \nu^3}{3h(2J + 1)} \left[ \frac{n(n^2 + 2)^2}{9} S_{ed} + n^3 S_{md} \right]$$

$\tau_{cal}$

$\beta_R$

$$\tau_{cal} = \frac{1}{A_T}$$

$$A_T = \sum A_R$$

$$\beta_R = \frac{A_R}{A_T}$$

$A_R$

Emission spectrum

$$\sigma_e = \frac{\lambda_p^4}{8\pi c n^2 \Delta \lambda_{eff}} A_R$$

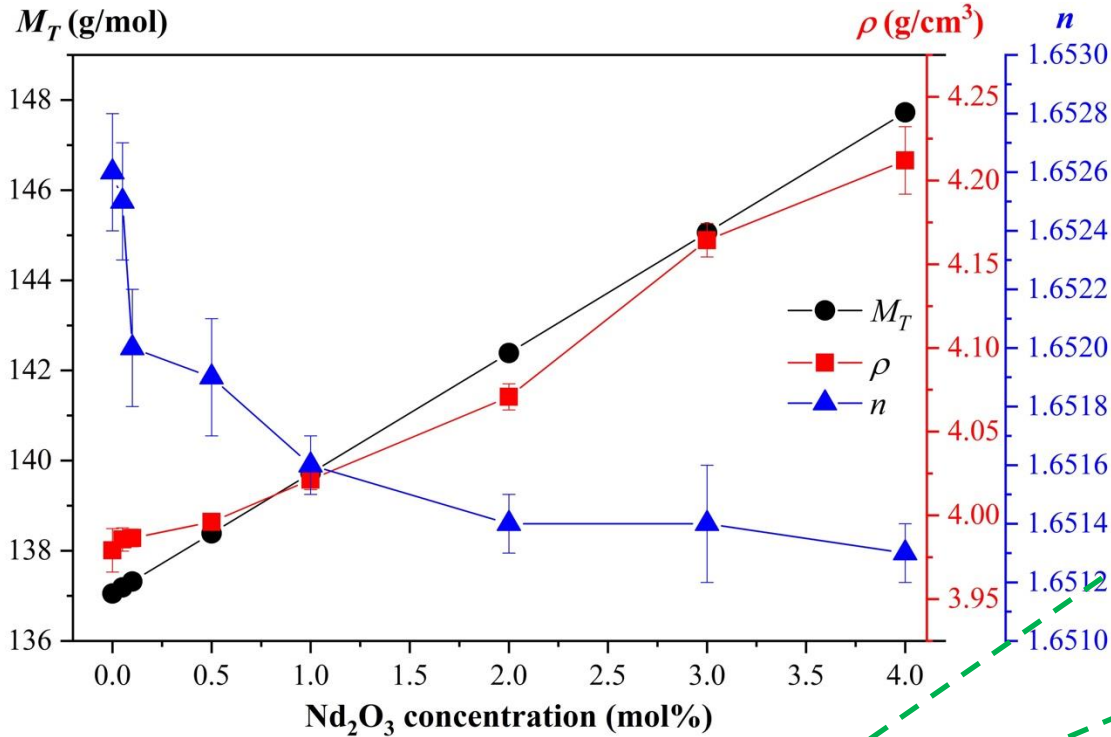
$\sigma$

$$S_{ed} = e^2 \sum_{\lambda=2,4,6} \Omega_\lambda |\langle \psi_J || U^\lambda || \psi'_{J'} \rangle|^2$$

$$S_{md} = \left( \frac{e^2 h^2}{16\pi^2 m^2 c^2} \right) |\langle \psi_J || L + 2S || \psi'_{J'} \rangle|^2$$

Parameter	Name	Indication or meaning
$f_{exp/cal}$	Oscillator strength	The experimental/calculated transition strength of $\text{Ln}^{3+}$ under photon absorption
$\Omega_2$	J-O parameter	- Asymmetric environment surround $\text{Ln}^{3+}$ - Covalency between $\text{Ln}^{3+}$ and ligand
$\Omega_4$ & $\Omega_6$		Viscosity and rigidity of glass
$A_R$ $\left( A_T = \sum A_R \right)$	Radiative transition probability	The transition probability (rate) of $\text{Ln}^{3+}$ cause photon emission
$\beta$	Branching ratio	Emission ratio and lasing power
$\sigma_{se}$	Stimulated emission cross-section	- Stimulated emission probability - Laser threshold (energy used to start the lasing action) - Gain laser application (ratio of output/input energy)
$\tau_R$	Radiative life time	Time of pure radiative transition
$\tau_{exp}$	Experimental life time	Time of radiative combined with non-radiative transition

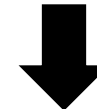
# Molecular mass ( $M_T$ ), Density ( $\rho$ ) & Refractive index ( $n$ )



Mass of  $\text{Nd}_2\text{O}_3 >$  Mass of  $\text{B}_2\text{O}_3$



$\text{B}_2\text{O}_3$  replacement by  $\text{Nd}_2\text{O}_3$   
make  $M_T$  of glass increase



$\rho$  increased with  
addition of  $\text{Nd}_2\text{O}_3$

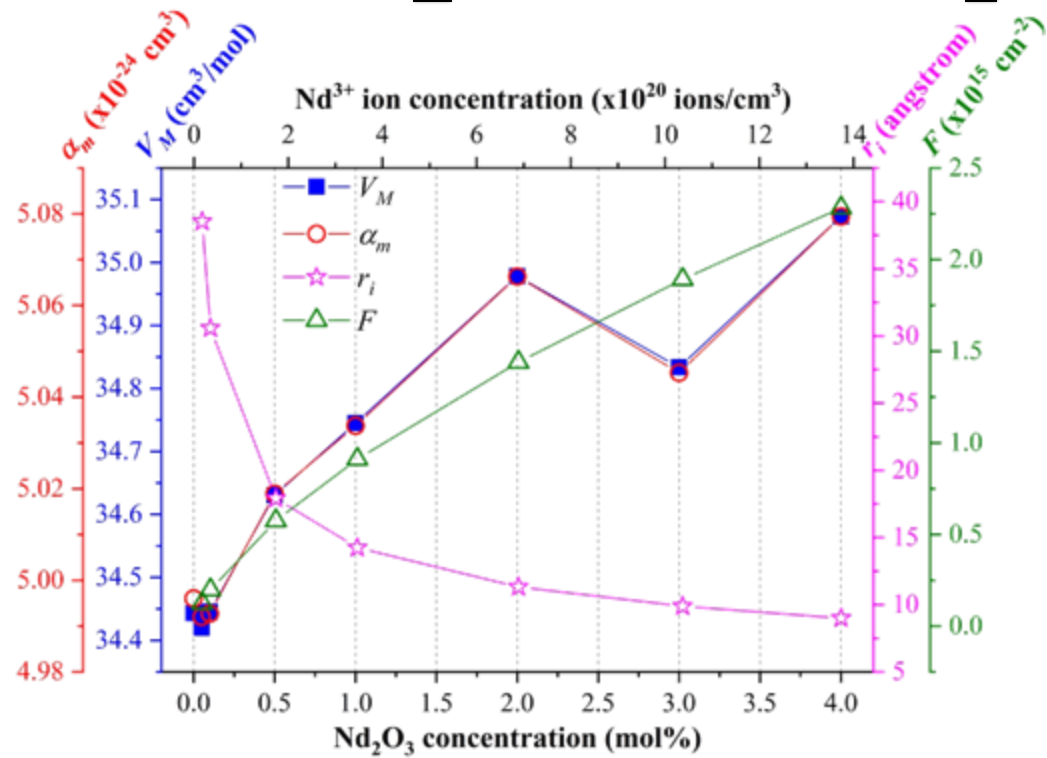
Lorentz – Lorentz relation

$$\frac{(n^2 - 1)}{(n^2 + 1)} = \left(\frac{\rho}{M_T}\right) R_m \quad \rightarrow \quad n \text{ decreases via } M_T \text{ addition}$$

Change of  $M_T$  is more effective than that of  $\rho$

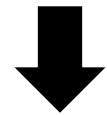
# Molar volume ( $V_M$ ), polarizability ( $\alpha_m$ ), Nd-Nd distance ( $r_i$ )

## & Field strength ( $F$ )

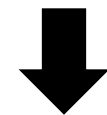


**Overview**  
(compare to undoped glass)

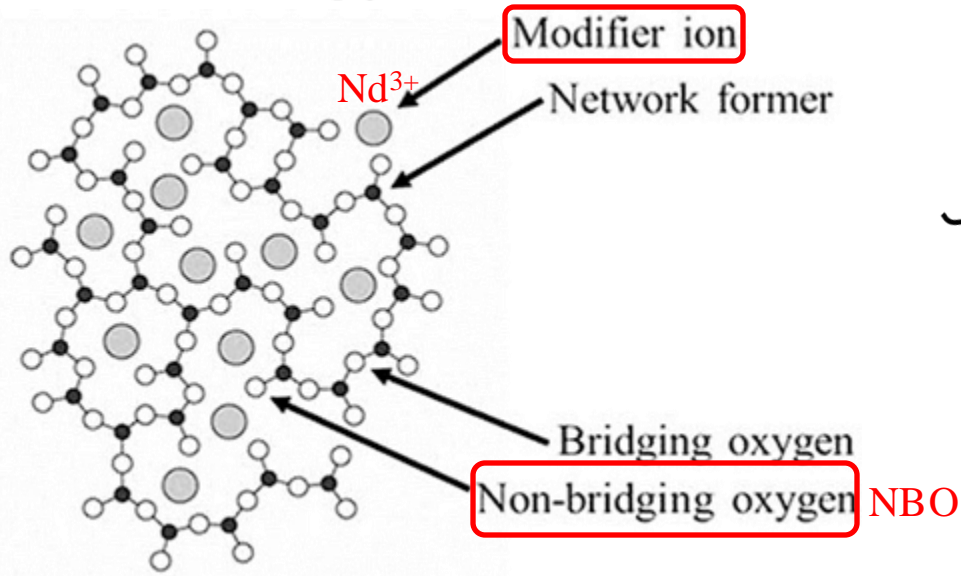
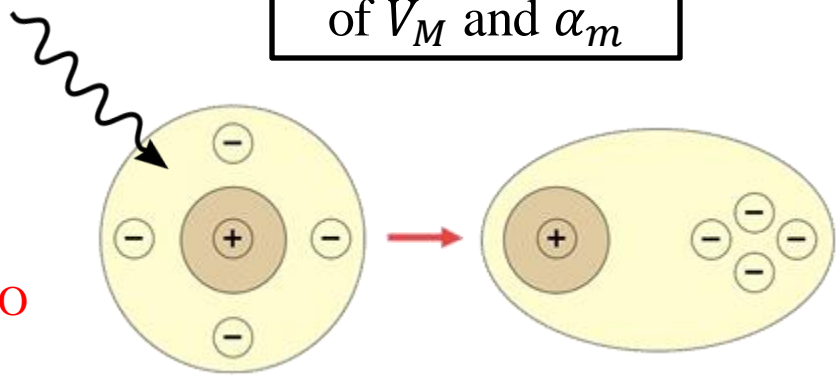
Nd<sub>2</sub>O<sub>3</sub> act as glass modifier



Adding Nd<sub>2</sub>O<sub>3</sub> create NBO and open space in glass network



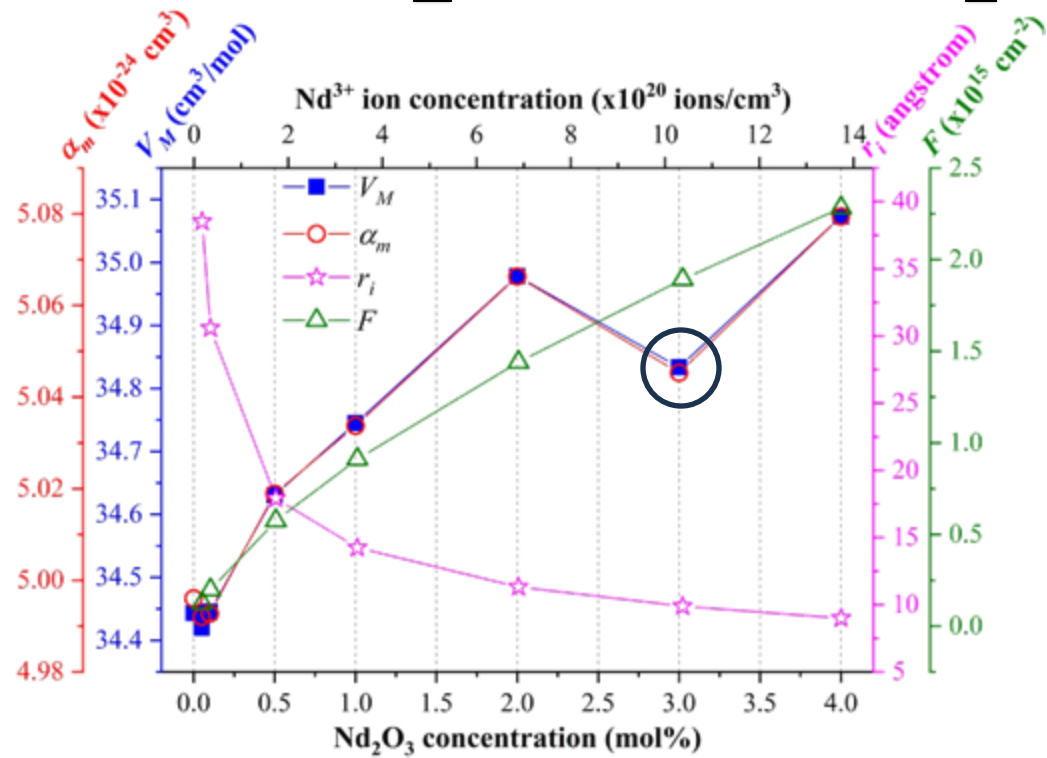
Increasing trend of  $V_M$  and  $\alpha_m$





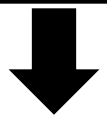
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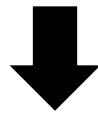


At  $x = 3$  mol%

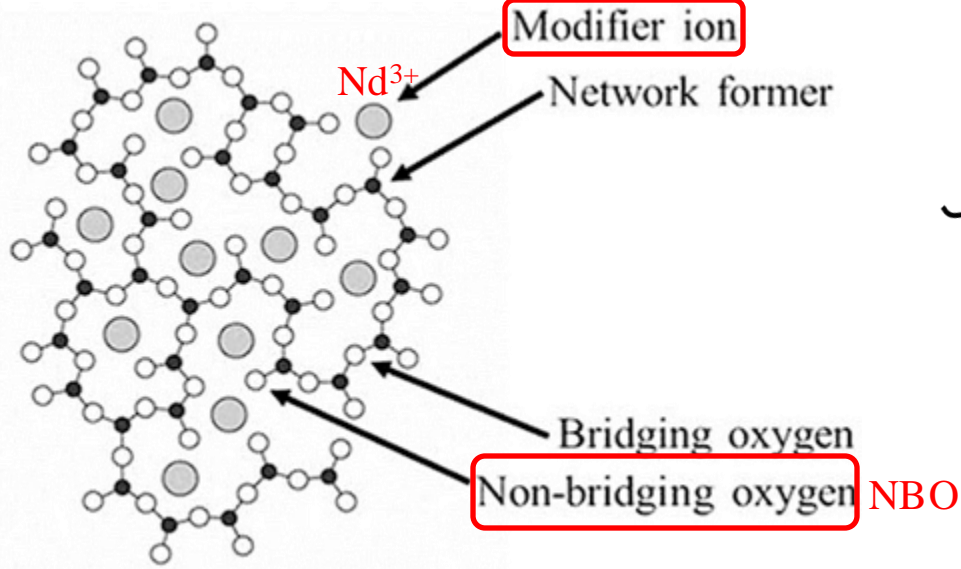
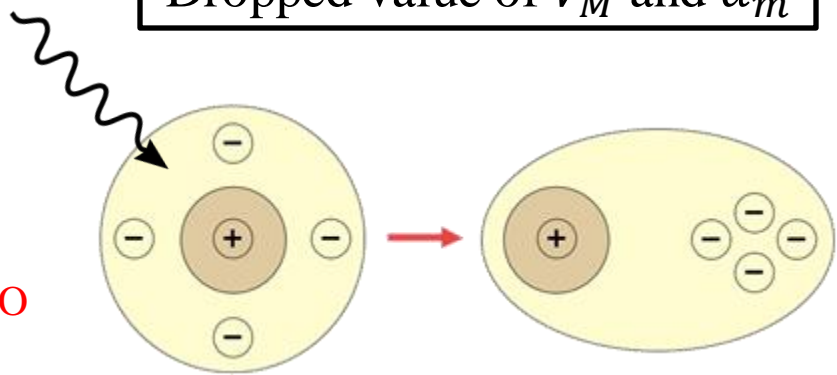
$\text{Nd}_2\text{O}_3$  acted as glass modifier but less effective than  $x = 2$  and  $4$  mol%

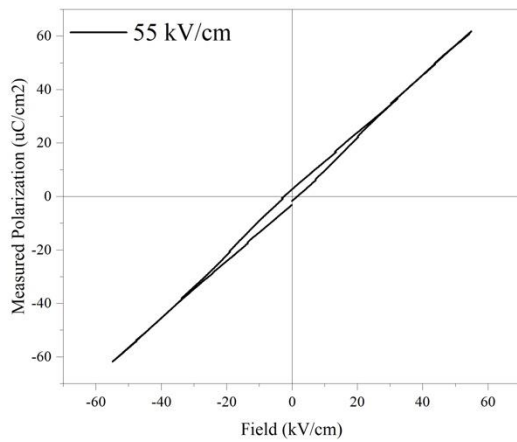
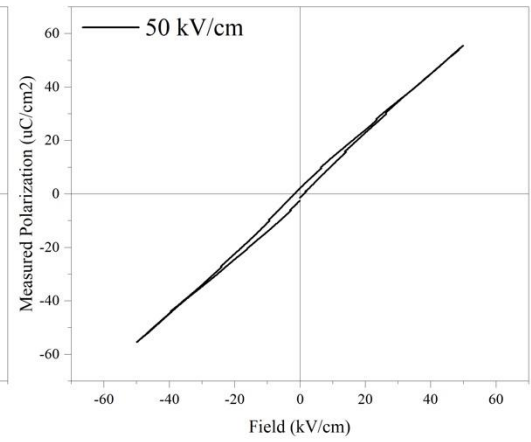
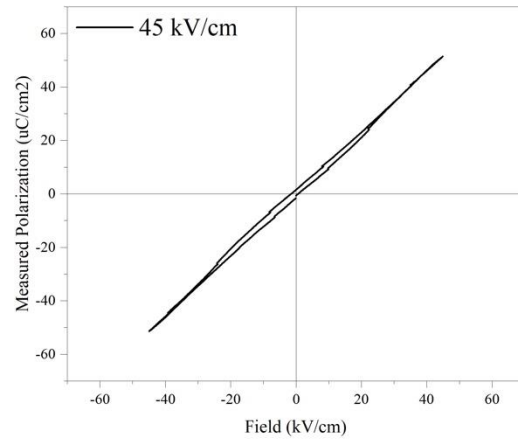
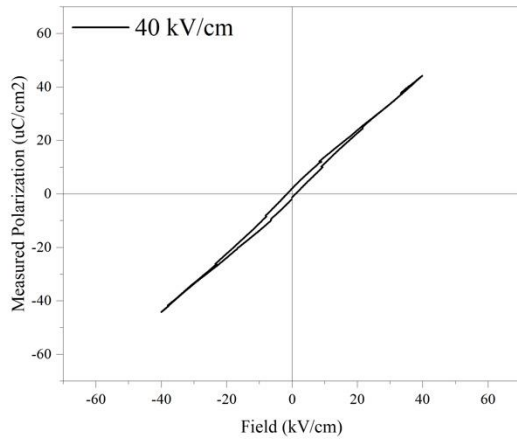
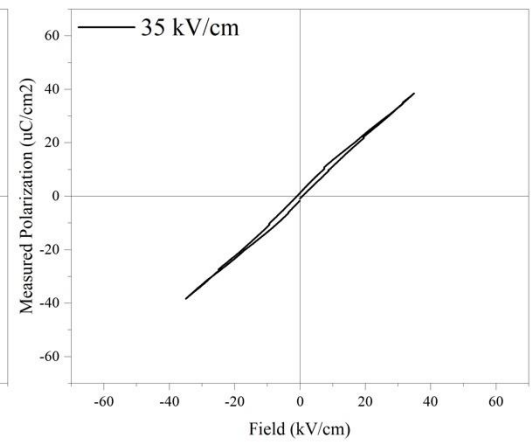
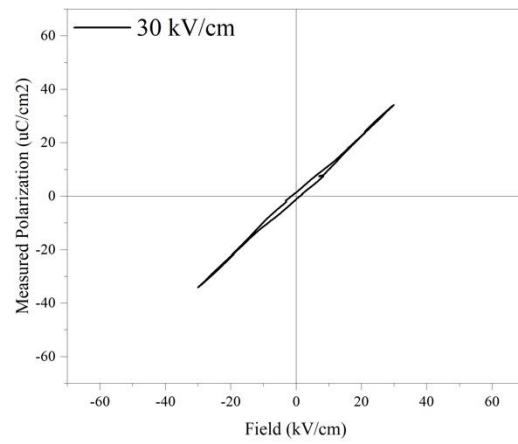
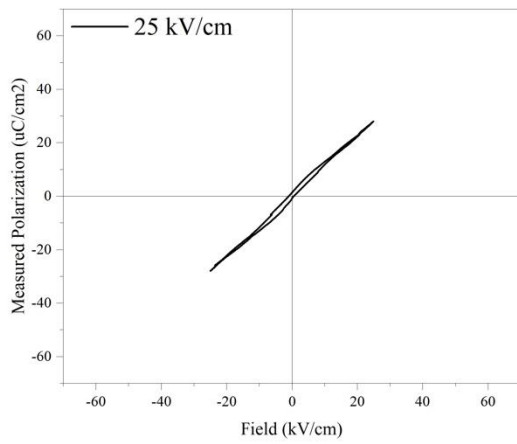


Less NBO and interstitial space in glass network than  $x = 2$  and  $4$  mol%

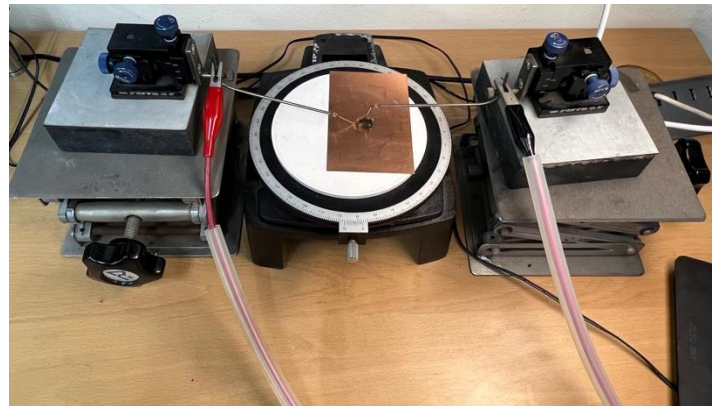


Dropped value of  $V_M$  and  $\alpha_m$



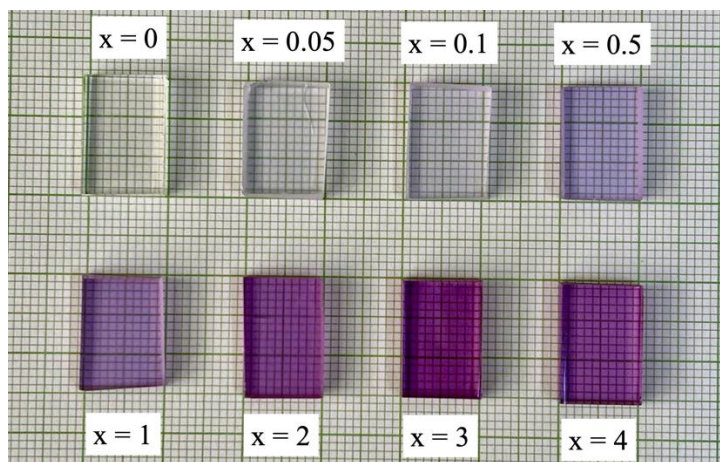
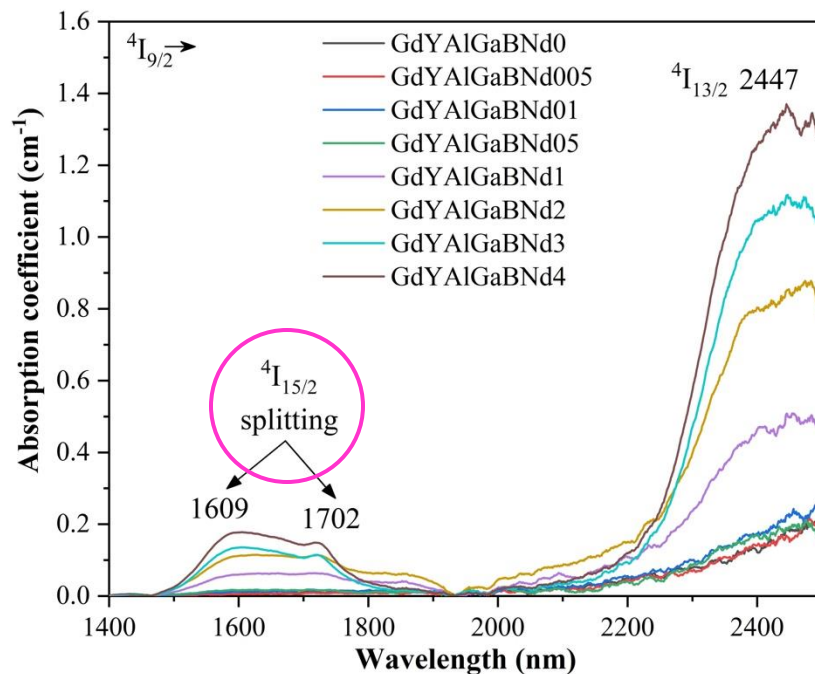
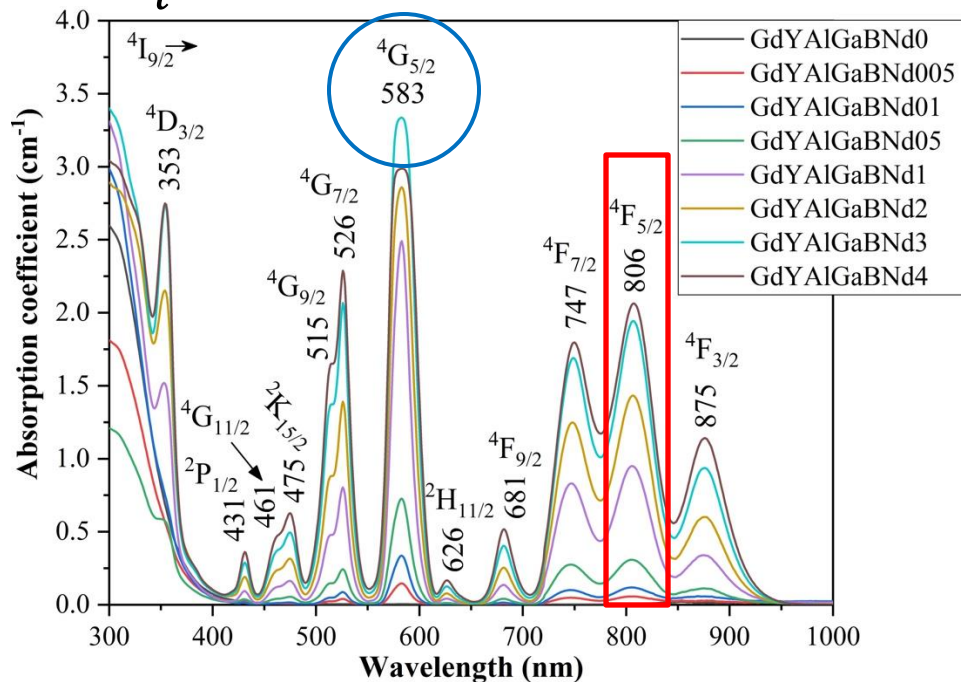


## Hysteresis (P-E) loop of GdYAlGaBNd1



$$\frac{A}{l} = \epsilon c$$

# Absorption spectra



- 14 transitions from  $4I_{9/2}$ , ground of  $Nd^{3+}$
- The strongest  $4I_{9/2} \rightarrow 5G_{5/2}$  hypersensitive (HS) transition at  $x = 3$  mol%



$Nd^{3+}$  environment is most asymmetry

- The ligand-field splitting for  $4I_{15/2}$  level in glass with  $x \geq 1$  mol%

# J-O analysis of GdYAlGaBNd1 glass (Absorption spectra)

Absorption wavelength (nm)	Transition $^4I_{9/2} \rightarrow$	GdYAlGaBNd1	
		$f_{exp}$ ( $\times 10^{-6}$ )	$f_{cal}$ ( $\times 10^{-6}$ )
431	$^2P_{1/2}$	0.80	0.82
461	$^4G_{11/2}$	0.82	0.37
475	$^2K_{15/2}$	2.26	0.54
515	$^4G_{9/2}$	4.54	2.43
526	$^4G_{7/2}$	5.42	5.51
583	$^4G_{5/2}$	23.89	23.86
681	$^4F_{9/2}$	0.89	0.99
747	$^4F_{7/2}$	8.95	9.00
806	$^4F_{5/2}$	9.78	10.18
875	$^4F_{3/2}$	3.05	3.47
	$\sigma_{rms}$	0.89	

$$\Omega_2 = 6.44 \times 10^{-20} \text{ cm}^2$$

$$\Omega_4 = 5.91 \times 10^{-20} \text{ cm}^2$$

$$\Omega_6 = 9.12 \times 10^{-20} \text{ cm}^2$$

$$\chi = \Omega_4 / \Omega_6 = 0.65$$



$$^4F_{3/2} \rightarrow ^4I_{11/2}$$

$$\lambda_{em} = 1064 \text{ nm}$$



$$^4F_{3/2} \rightarrow ^4I_{9/2}$$

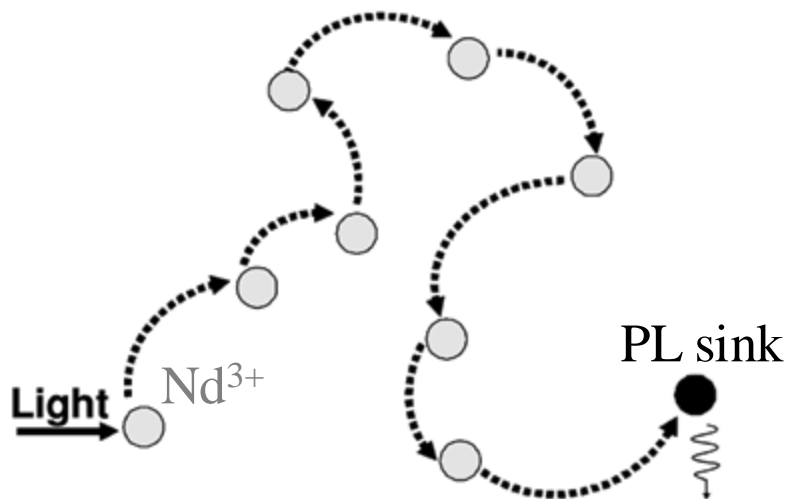
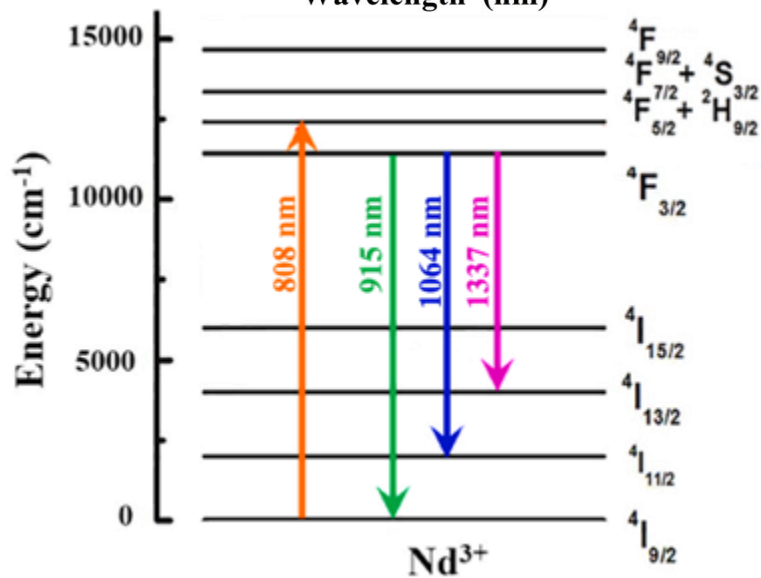
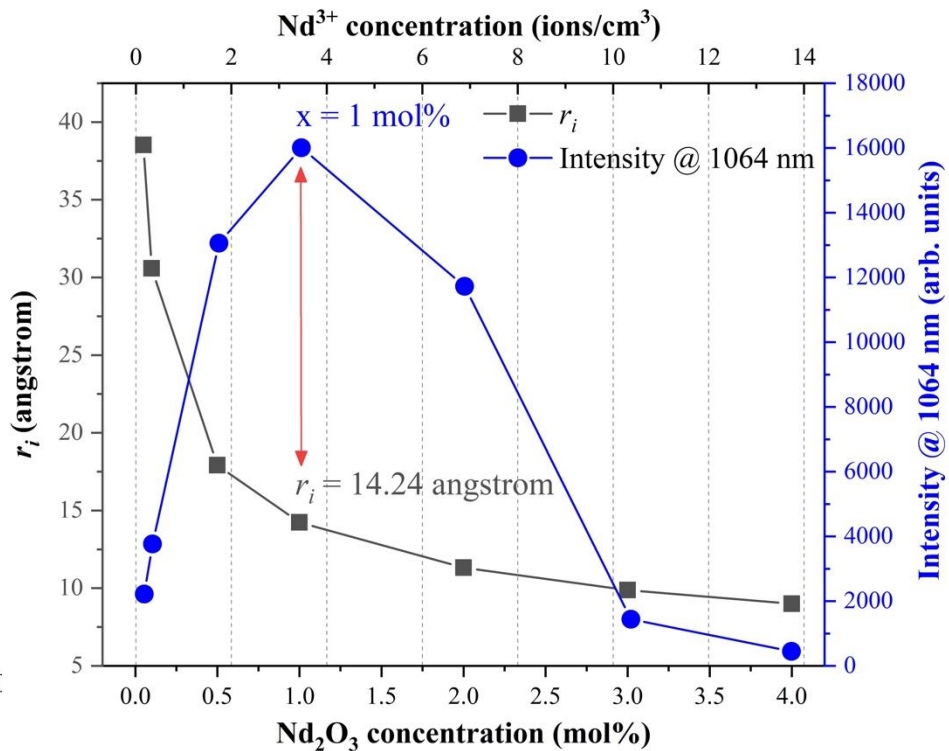
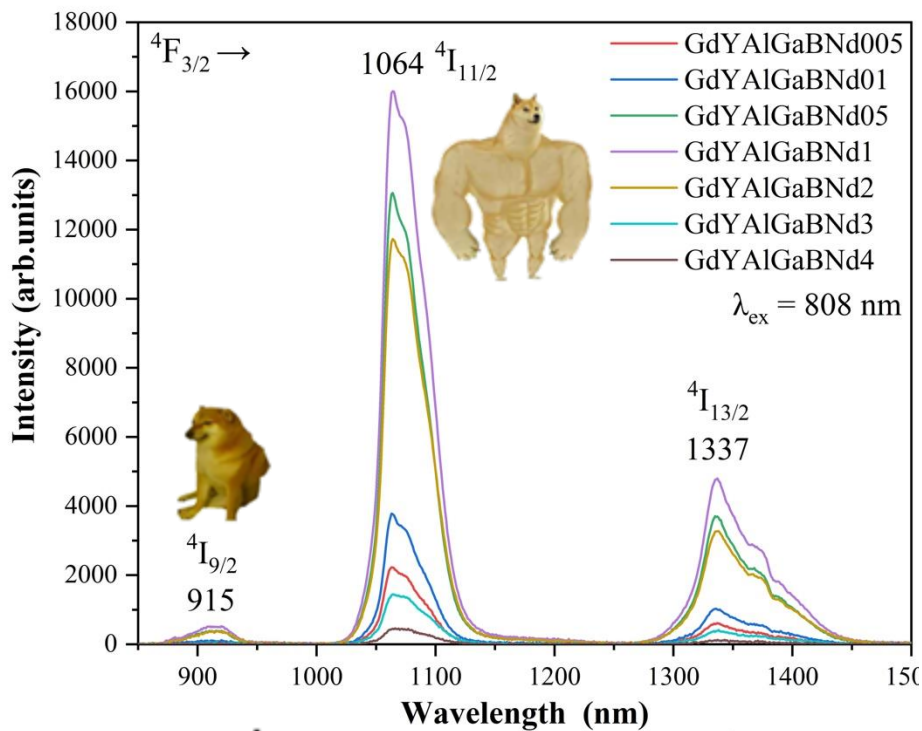
$$\lambda_{em} = 915 \text{ nm}$$



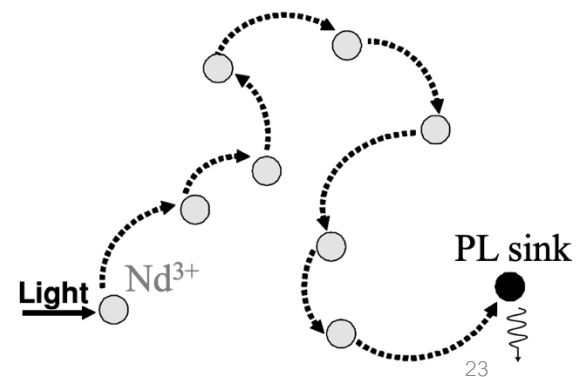
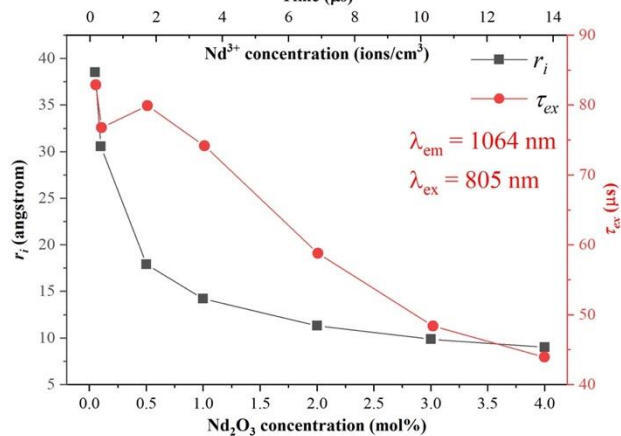
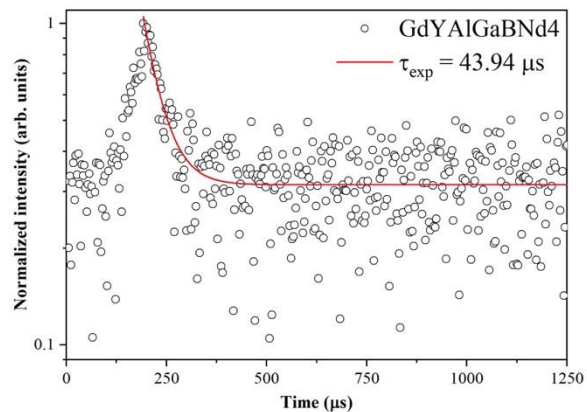
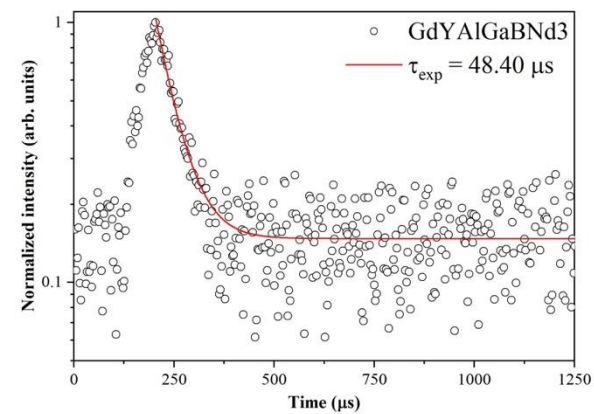
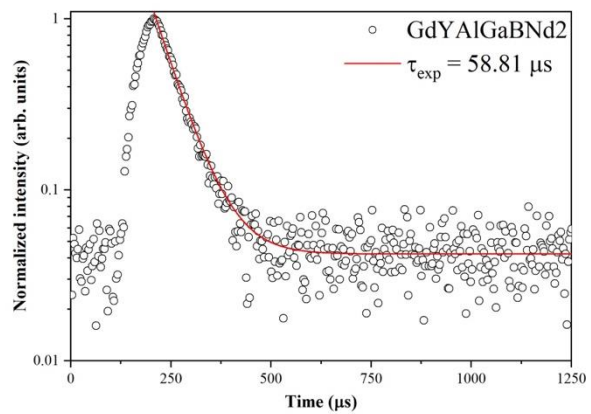
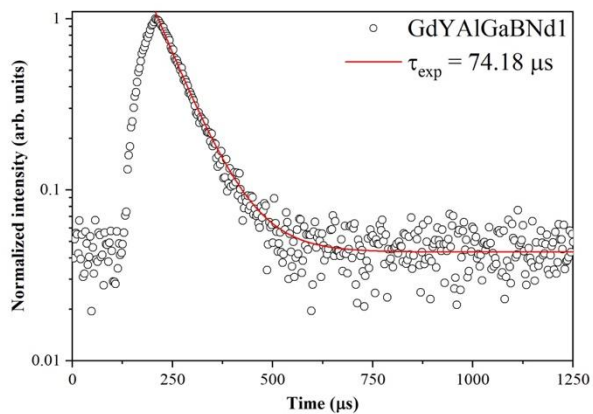
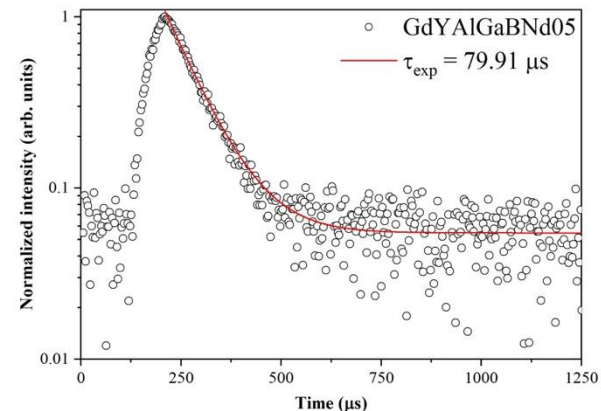
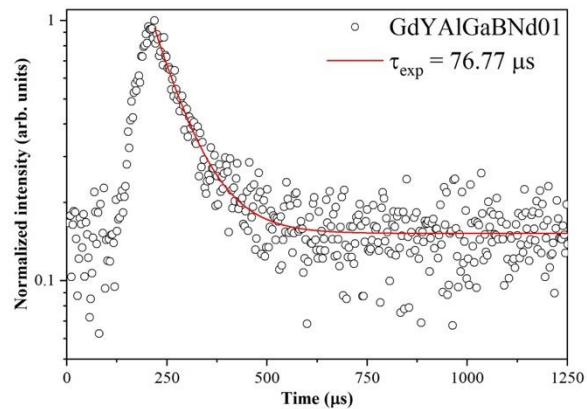
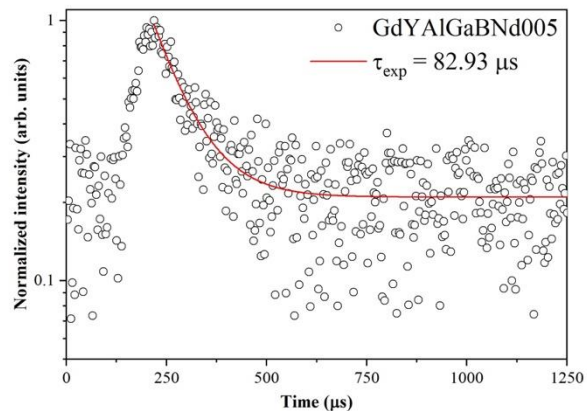
# Comparison of J-O parameters

Glass	$\Omega$ ( $\times 10^{-20}$ cm <sup>2</sup> )			$\chi$	Ref.
	$\Omega_2$	$\Omega_4$	$\Omega_6$		
GdYAlGaBNd1	6.44	5.91	9.12	0.65	This work
Hoya LHG-80	3.60	5.00	5.50	0.91	A. Jose, et al. 2022
Schott LG-770	4.30	5.00	5.60	0.89	A. Jose, et al. 2022
Kigre Q88	3.30	5.10	5.60	0.91	A. Jose, et al. 2022
PbFBaFAlB:Nd	5.77	3.68	4.01	0.91	P.R. Rani, et al. 2021
PbGe:Nd	5.61	6.34	6.42	0.99	A. Herrera, et al. 2021
NaKFCaFAlCaP:Nd	7.35	6.89	9.70	0.71	J. Rajagukguk, et al. 2019
BaZnLiFNaFLiB:Nd	8.68	7.97	12.75	0.62	G. Lakshminarayana, et al. 2022
NbKZnFLiFSi:Nd	10.26	6.38	6.06	1.05	D. Ramachari, et al. 2014

# Photoluminescence (PL) spectra



# PL decay time



# J-O analysis of GdYAlGaBNd1 glass (Emission spectra)

$\lambda_{em}$ (nm)	Transition ${}^4F_{3/2} \rightarrow$	GdYAlGaBNd1			
		$A_R$ ( $s^{-1}$ )	$\Delta\lambda_{eff}$ (nm)	$\sigma_{se}$ ( $\times 10^{-20} \text{ cm}^2$ )	$\beta_{exp}$
915	${}^4I_{9/2}$	2052	42.31	1.65	0.02
<b>1064</b>	${}^4I_{11/2}$	<b>2948</b>	<b>45.39</b>	<b>4.05</b>	<b>0.69</b>
1337	${}^4I_{13/2}$	606	63	1.48	0.29

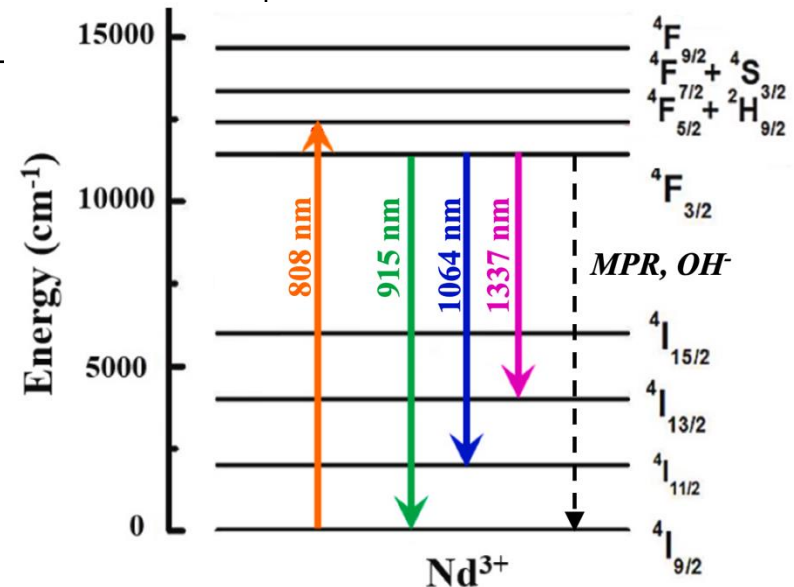
Highest probability for stimulated emission

Winner for competitively emission transition

$\tau_R$  for  ${}^4F_{3/2}$  level = 177.40  $\mu s$

Quantum efficiency ( $\eta$ )

$$\eta = \frac{\tau_{exp}}{\tau_R} \times 100 = \frac{74.18}{177.40} \times 100 = 41.82 \%$$



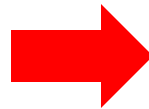


# Comparison of radiative parameters

Glass	$\Delta\lambda_{\text{eff}}$ (cm)	$\sigma_{\text{se}}$ ( $\times 10^{-20} \text{ cm}^2$ )	$\Delta\lambda_{\text{eff}} \times \sigma_{\text{se}}$ ( $\times 10^{-25} \text{ cm}^3$ )	$\tau_{\text{exp}}$ ( $\mu\text{s}$ )	$I_s$ ( $\times 10^8 \text{ W/m}^2$ )	$\eta$ (%)
GdYAlGaBNd1	45.39	4.05	1.84	74.18	6.22	41.82
Hoya LHG-80	23.90	4.20	1.00	-	-	-
Schott LG-770	25.40	3.90	0.99	-	-	-
Kigre Q88	21.90	4.00	0.88	-	-	-
PbFBaFAlB:Nd	34.80	7.23	2.52	245	1.04	90.00
PbGe:Nd	37.33	4.52	1.69	88	4.64	64.00
NaKFCaFAlCaP:Nd	33.22	4.92	1.63	200	1.87	98.92
BaZnLiFNaFLiB:Nd	32.46	2.60	0.84	62	11.44	17.00
NbKZnFLiFSi:Nd	38.00	4.30	1.63	135	3.18	78.00

## Character of GdYAlGaBNd1 glass

- Wide  $\Delta\lambda_{\text{eff}}$  and  $\Delta\lambda_{\text{eff}} \times \sigma_{\text{se}}$
- Fair  $\sigma_{\text{se}}$  and  $I_s$
- Quite Short  $\tau_{\text{exp}}$



## Approach to applications

- Potential optical amplifier
- Interesting laser medium

## Point to improve

- Upgrade  $\eta$

## Conclusion

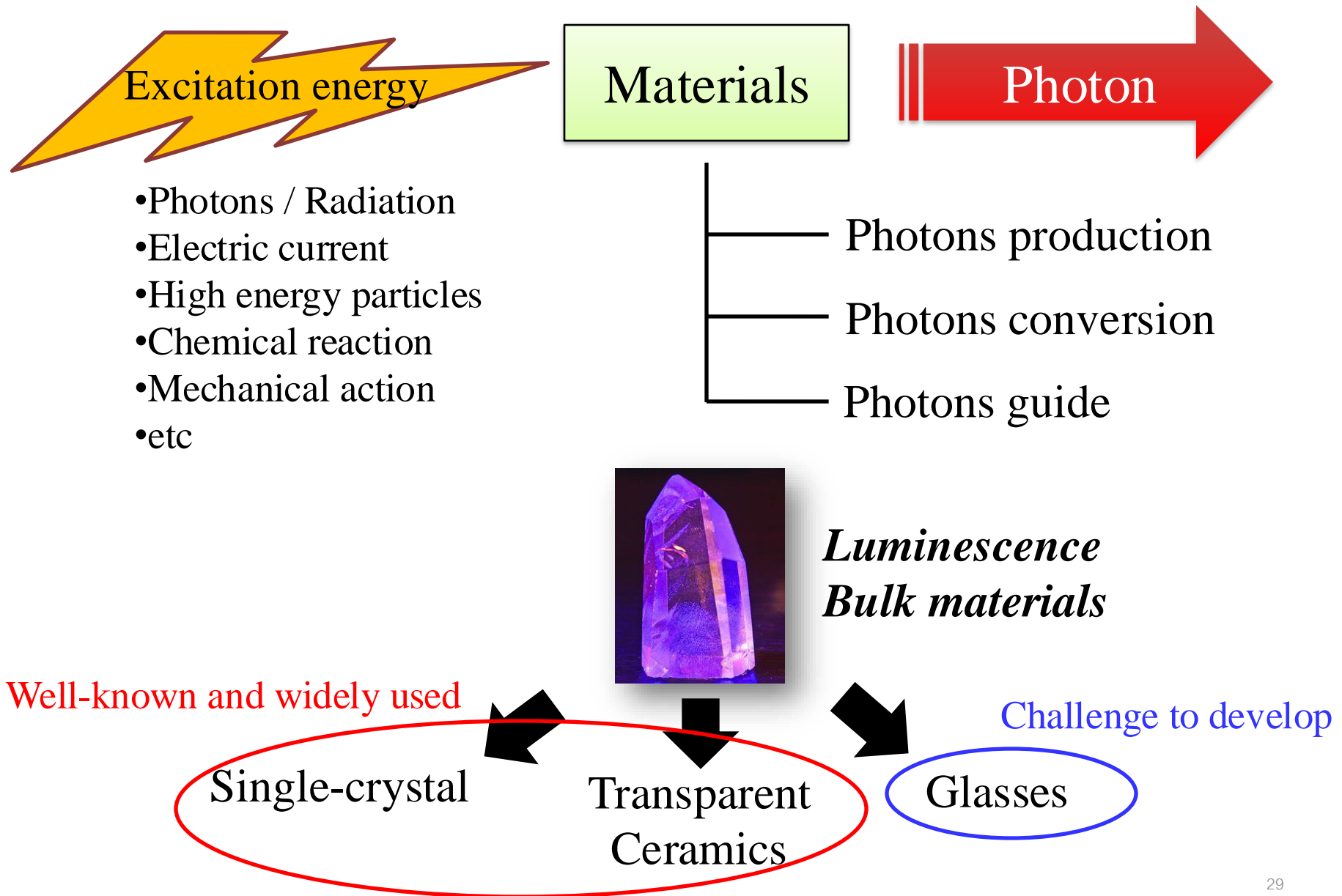
- $\text{Nd}_2\text{O}_3$  addition  $\rightarrow$  more density but less refractive index
- Overview behavior:  $\text{Nd}_2\text{O}_3$  is glass modifier for GdYAlGaB glass
- GdYAlGaBNd glass is weak paraelectric material
- The optimum  $\text{Nd}_2\text{O}_3$  concentration : 1 mol%
- Strong absorption at 806 nm produces the strong luminescence at 1064 nm with decay time  $\sim 74 \mu\text{s}$
- Judd-Ofelt analysis: potential amplifier for laser and optical telecommunication

## **Acknowledgement**

- Muban Chombueng Rajabhat University (MCRU)
- Center of Excellence in Glass Technology and Materials Science (CEGM) Nakhon Pathom Rajabhat University (NPRU)
- This work has been supported by Thailand Science Research and Innovation (TSRI) in project No. 194462 (2024).

**Thank you**

# Luminescence materials for photonics



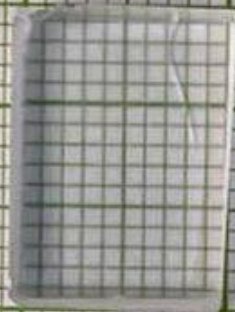
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18																		
1	1 <b>H</b> Hydrogen 1.00794	Atomic # Symbd Name Atomic Mass																2 <b>He</b> Helium 4.002602																		
2	3 <b>Li</b> Lithium 6.941	4 <b>Be</b> Beryllium 9.012182	<b>C</b> Solid <b>Hg</b> Liquid <b>H</b> Gas <b>Rf</b> Unknown										<b>Metals</b> Alkali metals Alkaline earth metals Lanthanoids Actinoids Transition metals Poor metals			<b>Nonmetals</b> Other nonmetals Noble gases				5 <b>B</b> Boron 10.811	6 <b>C</b> Carbon 12.0107	7 <b>N</b> Nitrogen 14.0067	8 <b>O</b> Oxygen 15.9994	9 <b>F</b> Fluorine 18.9984032	10 <b>Ne</b> Neon 20.1797											
3	11 <b>Na</b> Sodium 22.98976928	12 <b>Mg</b> Magnesium 24.3050	19 <b>K</b> Potassium 39.0983	20 <b>Ca</b> Calcium 40.078	21 <b>Sc</b> Scandium 44.955912	22 <b>Ti</b> Titanium 47.887	23 <b>V</b> Vanadium 50.9415	24 <b>Cr</b> Chromium 51.9961	25 <b>Mn</b> Manganese 54.938045	26 <b>Fe</b> Iron 55.845	27 <b>Co</b> Cobalt 58.933195	28 <b>Ni</b> Nickel 58.6934	29 <b>Cu</b> Copper 63.546	30 <b>Zn</b> Zinc 65.38	31 <b>Ga</b> Gallium 69.723	32 <b>Ge</b> Germanium 72.64	33 <b>As</b> Arsenic 74.92160	34 <b>Se</b> Selenium 78.96	35 <b>Br</b> Bromine 79.904	36 <b>Kr</b> Krypton 83.798																
4	37 <b>Rb</b> Rubidium 85.4678	38 <b>Sr</b> Strontium 87.62	39 <b>Y</b> Yttrium 88.90585	40 <b>Zr</b> Zirconium 91.224	41 <b>Nb</b> Niobium 92.90638	42 <b>Mo</b> Molybdenum 95.96	43 <b>Tc</b> Technetium (97.9072)	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.90550	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.8682	48 <b>Cd</b> Cadmium 112.411	49 <b>In</b> Indium 114.818	50 <b>Sn</b> Tin 118.710	51 <b>Sb</b> Antimony 121.760	52 <b>Te</b> Tellurium 127.60	53 <b>I</b> Iodine 126.90447	54 <b>Xe</b> Xenon 131.293	55 <b>Ba</b> Barium 137.327	56 <b>La</b> Lanthanum 138.90547	57-71	72 <b>Hf</b> Hafnium 178.49	73 <b>Ta</b> Tantalum 180.94788	74 <b>W</b> Tungsten 183.84	75 <b>Re</b> Rhenium 186.207	76 <b>Os</b> Osmium 190.23	77 <b>Ir</b> Iridium 192.217	78 <b>Pt</b> Platinum 195.084	79 <b>Au</b> Gold 196.966569	80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.3833	82 <b>Pb</b> Lead 207.2	83 <b>Bi</b> Bismuth 208.98040	84 <b>Po</b> Polonium (209.9824)	85 <b>At</b> Astatine (209.9871)	86 <b>Rn</b> Radon (222.0176)
5	87 <b>Fr</b> Francium (223)	88 <b>Ra</b> Radium (226)	89-103	104 <b>Rf</b> Rutherfordium (261)	105 <b>Db</b> Dubnium (262)	106 <b>Sg</b> Seaborgium (266)	107 <b>Bh</b> Bohrium (264)	108 <b>Hs</b> Hassium (277)	109 <b>Mt</b> Meitnerium (268)	110 <b>Ds</b> Darmstadtium (271)	111 <b>Rg</b> Roentgenium (272)	112 <b>Uub</b> Ununbium (285)	113 <b>Uut</b> Ununtrium (284)	114 <b>Uuq</b> Ununquadium (289)	115 <b>Uup</b> Ununpentium (288)	116 <b>Uuh</b> Ununhexium (282)	117 <b>Uus</b> Ununseptium	118 <b>Uuo</b> Ununoctium (294)																		
6	57 <b>La</b> Lanthanum 138.90547	58 <b>Ce</b> Cerium 140.116	59 <b>Pr</b> Praseodymium 140.90765	60 <b>Nd</b> Neodymium 144.242	61 <b>Pm</b> Promethium (145)	62 <b>Sm</b> Samarium 150.36	63 <b>Eu</b> Europium 151.964	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.92535	66 <b>Dy</b> Dysprosium 162.500	67 <b>Ho</b> Holmium 164.93032	68 <b>Er</b> Erbium 167.259	69 <b>Tm</b> Thulium 168.93421	70 <b>Yb</b> Ytterbium 173.054	71 <b>Lu</b> Lutetium 174.9668																					
7	89 <b>Ac</b> Actinium (227)	90 <b>Th</b> Thorium 232.03806	91 <b>Pa</b> Protactinium 231.03688	92 <b>U</b> Uranium 238.02891	93 <b>Np</b> Neptunium (237)	94 <b>Pu</b> Plutonium (244)	95 <b>Am</b> Americium (243)	96 <b>Cm</b> Curium (247)	97 <b>Bk</b> Berkelium (247)	98 <b>Cf</b> Californium (251)	99 <b>Es</b> Einsteinium (252)	100 <b>Fm</b> Fermium (257)	101 <b>Md</b> Mendelevium (258)	102 <b>No</b> Nobelium (259)	103 <b>Lr</b> Lawrencium (262)																					

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

$x = 0$



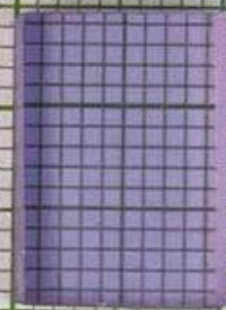
$x = 0.05$



$x = 0.1$



$x = 0.5$



$x = 1$



$x = 2$



$x = 3$



$x = 4$



# Aluminium garnet compound family

$Y_3Al_5O_{12}$  (YAG) : 1960s



$Lu_3Al_5O_{12}$  (LuAG) : 1990s



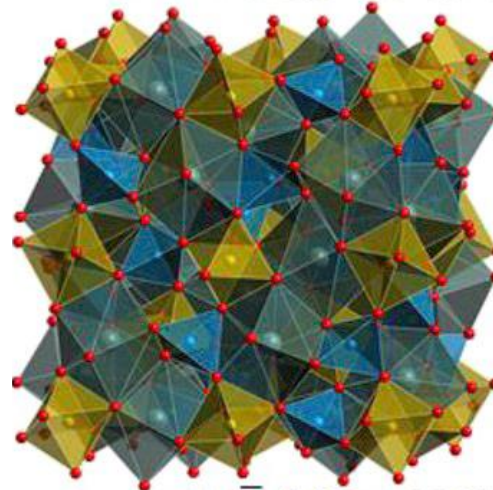
$A_3(B,C)_5O_{12}$  : Until present

Possible A element = Y, Lu, Gd, Sc or mixing between them

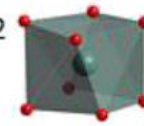
Possible B & C element = Al, Ga, Sc or mixing between them

*Cubic crystalline structure*

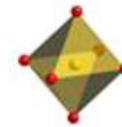
Garnet,  $\{A\}_3\{B\}_2\{C\}_3O_{12}$



$Ia\bar{3}d$  (No. 230)



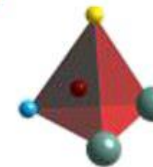
Dodecahedral (8 fold)  
{A} site...24c site



Octahedral (6 fold)  
[B] site ...16a site



Tetrahedral (4 fold)  
(C) site...24d site



Tetrahedral (4 fold)  
anion site...96h site

Ueda, J., Tanabe, S. (2019). Optical Materials: X, 1, 100018

Multi-component garnet



# Luminescence glass material

$\text{Ln}^{3+}$

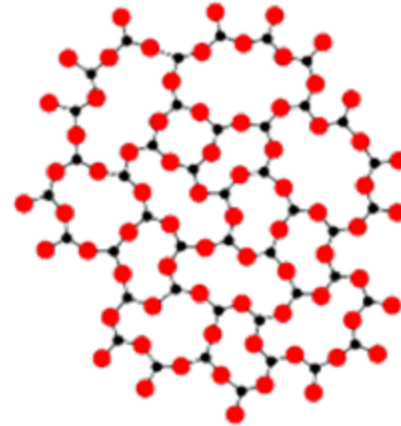


Require

the excellent luminescence center



Difficult for self-emission  
with strong light signal ←



Glassy  $\text{A}_2\text{O}_3$

**Glass**

**Amorphous** structure

**Unclear** electronic bandgap

**Easy** for preparation

Can prepare in **various sizes** and **shapes**  
with same properties

**Wide range** of chemical ratio

**Low** production cost

# Luminescence glass material

57 <b>La</b> Lanthanum 138.90547	58 <b>Ce</b> Cerium 140.116	59 <b>Pr</b> Praseodymium 140.90765	60 <b>Nd</b> Neodymium 144.242	61 <b>Pm</b> Promethium (145)	62 <b>Sm</b> Samarium 150.36	63 <b>Eu</b> Europium 151.964	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.92535	66 <b>Dy</b> Dysprosium 162.500	67 <b>Ho</b> Holmium 164.93032	68 <b>Er</b> Erbium 167.259	69 <b>Tm</b> Thulium 168.93421	70 <b>Yb</b> Ytterbium 173.054	71 <b>Lu</b> Lutetium 174.9668
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$\text{Ln}^{3+}$



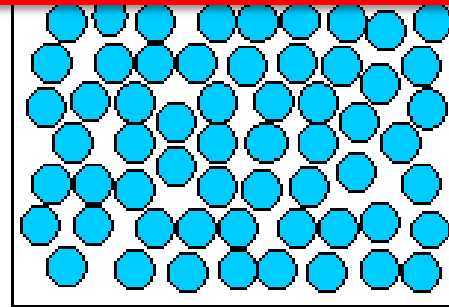
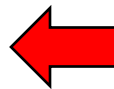
Require

the excellent luminescence center



Difficult for

intrinsic luminescence



**Glass**

**Amorphous / Random** structure

**Unclear** electronic bandgap & center

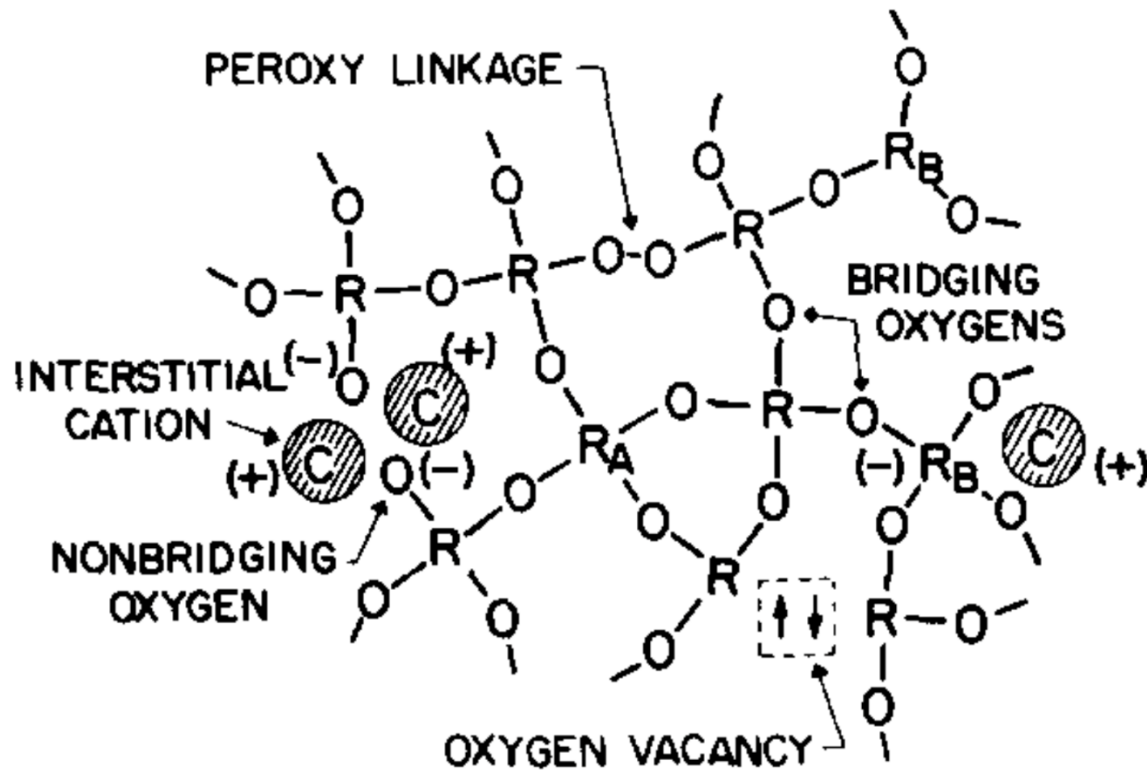
**Easy** for preparation

Can prepare in **various sizes** and **shapes** which the same properties

**Wide range** of chemical ratio

**Low** production cost

# Glass defect



$R, R_A, R_B$  = Network Formers = Si, B, P, Ge, Al, ...

C = Monovalent Network Modifying Cation = H, Li, Na, K, ...

# Glass preparation (melt - quenching)

