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# Study of Measurement of luminescence life time of the $Nd^{3+}$ ions in the 6-FDA/UVR and $Al_2o_3$ hosts

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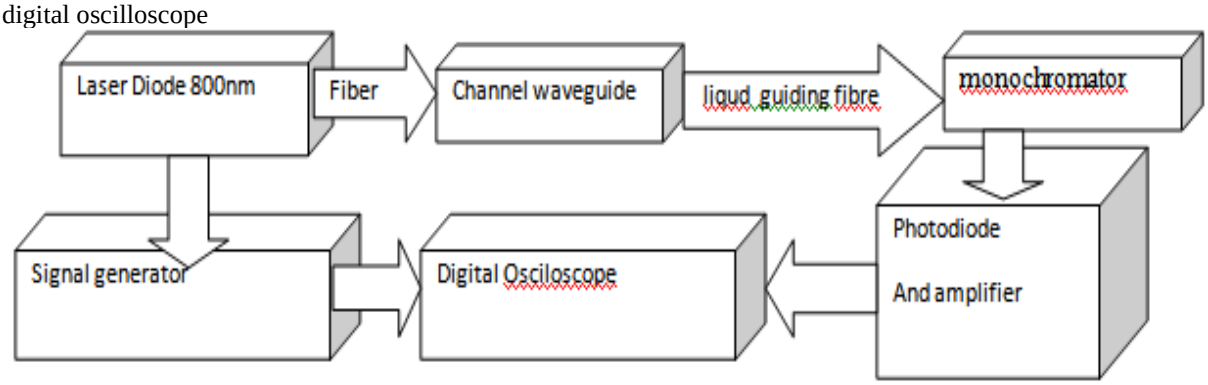
**ABSTRACT**
Luminescence life time measurements of the $Nd^{3+}$ ions in the 6-FDA/UVR and $Al_2o_3$ hosts were performed using a Laser diode emitting at 800nm as the excitation source. Optical losses in both materials have been studied and compared absorption bands of $Nd^{3+}$ have been observed at 580nm ,745nm, 800nm and 870nm . Based on which Judd- ofelt analysis has been applied to study the transition properties of $Nd^{3+}$ ions in the two hosts. Photoluminescence spectra of $Nd^{3+}$ have been experimentally studied and emission around 880nm, 1060nm and 1330nm is observed, which indicates that $Nd^{3+}$ ions are active in these two hosts.

**Keywords**:- luminescence life time, Excitation source, Laser diode, Optical loss, Photoluminescence, absorption bands etc

## I. Experiment

The Laser diode was modulated by an external square pulse generator and delivered pulses of 4µs duration, allowing the population of the $Nd^{3+}$ system to reach a steady state before the pump was switched of f. the pulse had a cut off time of below 5µs , which was much shorter of the luminescence life time of the $Nd^{3+}$ .the luminescence light was collected from the top surface of the wave guide by large core liquid fiber, and diffracted by monochromatic tuned to the peak wavelengths (880nm, 1060nm and 1330nm) the selected luminescence light was detected by an InGaAs photodiode. The signal was amplified and then acquired with a digital oscilloscope




(Setup used for measuring the luminescence life time in channel waveguides)
Fig1 shows the luminescent decay of $Nd^{3+}$ measured in 6-FDA/UVR at 1060nm of $Nd^{3+}$ concentration of $1.03x10^{20}cm^{-3}$

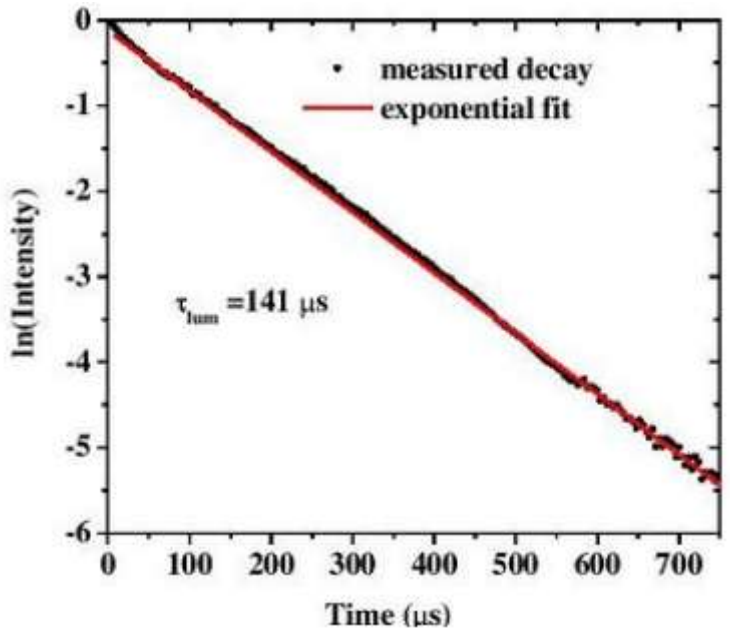
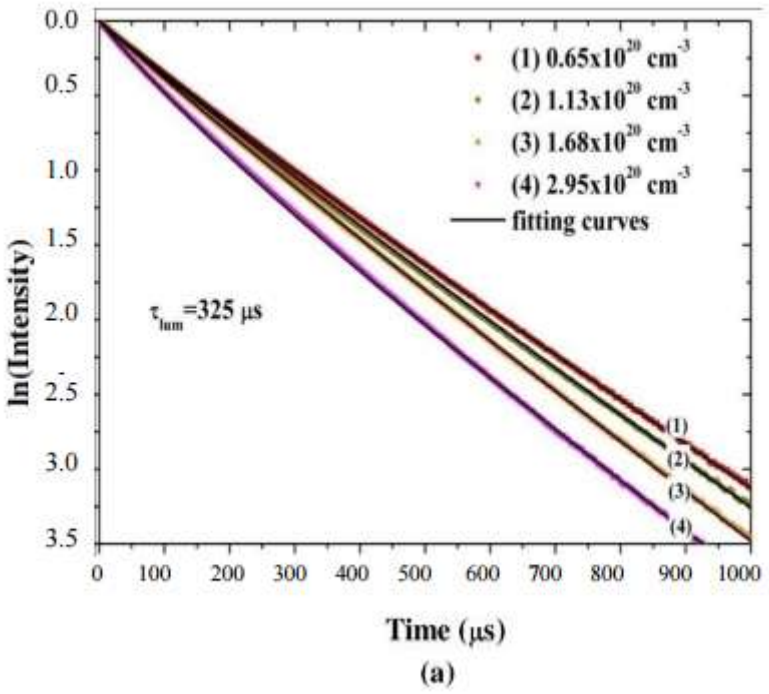



Fig1

Except for a faster decay occurring directly after switching of f the pump excitation (first 20 μs ) which is attributed to ETU between neighboring $Nd^{3+}$ in their $^4F_{3/2}$ excited levels[54] an exponential decay was observed. A luminescence life time of 4 ms at 1056 nm was derived from the exponential part of the decay curve, which was independent of the excitation intensity. this long life time demonstrates that luminescence quenching effects have been largely diminished by the choice of complex and surrounding polymer material. Further more, encapsulating the $Nd^{3+}$ ions may well contribute to diminishing the effect of ETU by ensuring a rather large distance between nearest neighbor $Nd^{3+}$ ions the long, unquenched excited state life time of $Nd^{3+}$ ions in this specific environment sets the stage for the successful gain demonstration as well as continuous wave polymer laser experiments. Much stronger intensity of the luminescence light can be collected from $Al_2o_3$ is to $Nd^{3+}$ samples without top cladding layer than that measured in polymer samples of top cladding layer . Luminescence of decay of $Nd^{3+}$ ions in $Al_2o_3$ channel waveguides was measured with various ions concentrations and is given in fig 2(a)

In the decay curve (1) of the lowest concentration, except for a faster decay occurring directly after switching off the pump excitation first approximately 50 ms in fig 2(a), which is attributed to ETU between neighboring ND ions in their $^4F_{3/2}$ excited levels (88,89) an exponential decay was observed. A luminescence life time of 325 ms was derived from the exponential part of the decay curve at 1065 nm, which was independent of the excitation intensity. It is of the same order of the magnitude as the radioactive life time of 474 ms calculated by judd-ofelt analysis however the decay curve (2)-(4) at higher $Nd^{3+}$ ions concentration cannot be fitted with an exponential curve mainly due to the effect of ETU.



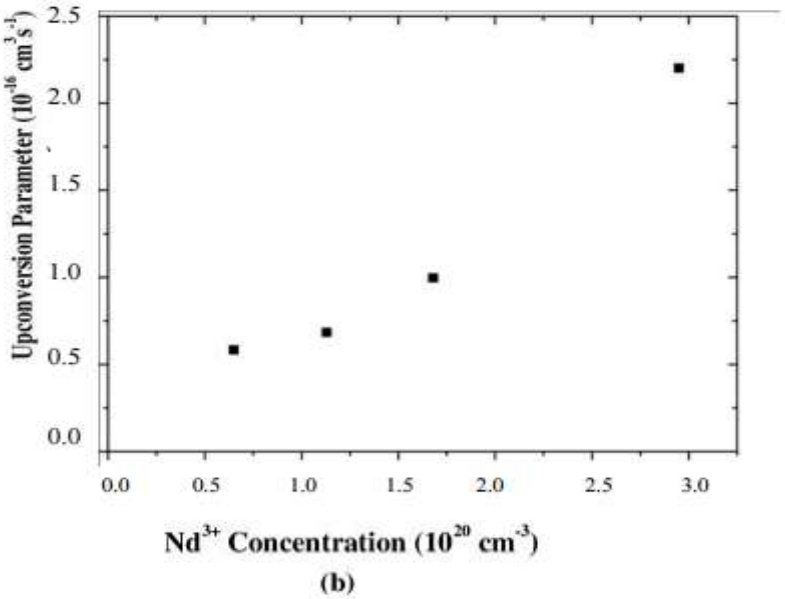




Fig 2

Three ETU processes of energy levels of $Nd^{3+}$ ions originating in the metastable $^4F_{3/2}$ level of $Nd^{3+}$ system where taken into account and expressed by single macroscopic parameter WETU in the simulation, these processes leave to similar results concerning the population dynamics in the $Nd^{3+}$ ions system a known exponential model based on the Bernoulli equation was applied to determine the ETU parameter. By setting the pump and signals terms to zero and solving rate equations time dependently.

Rate equation

$$\frac{dN4}{dt} = R_{05} - R_{40} + R_{05} - t_4^{-1} - R_{04} - W_{ETU} N^2_4 \quad \text{----------(1)}$$

$$\frac{dN4}{dt} = R_{05} - R_{41} - t_4^{-1} - W_{ETU}, N_0$$

Bernoulli equation is derived

$N(t)\frac{N0\exp(-\frac{t}{\tau})}{1+W}$

The intrinsic life time $\tau_4$ equals the luminescence life time obtained from the exponential decay at very low dopant concentration, it remains constant at all dopant concentrations.

ETU parameters were determined by fitting equation (2) to the measured luminescence decay curves. The fitted curves show very good agreement with the measured decay curves at 1064nm fig 2(a) which an indication that this simplified model is valid for ETU in the $Al_2o_3 : Nd^{3+}$ system with this method, valued of the ETU parameters of 0.58,0.68,1.00 and $2.20x10^{-16}cm^3/s$ were determined at $Nd^{3+}$ concentrations of 0.65,1.13,1.68 and $2.95x10^{20}$ $cm^{-3}$ respectively. The main fitting error of the ETU parameters in this approach could be the deviation of the starting fitting point, due the fluctuation of the excitation laser output. For direct excitation the quantum efficiency (q) is defined as

$\eta_q=\frac{emitted\ light\ intensity}{absorved\ pum\ intensity}$

in most of the cases the quantum efficiency ($\eta_q$) is lower than one due to the non radiative quenching. High quantum efficiency is required for efficient amplification and lasing. The quantum efficiency can be calculated from measured luminescence lifetime $\tau_{lum}$ and calculated radiative life time $\tau_{rad}$ using judd-ofelt

theory by the equation

$\eta_q\frac{\tau lum}{\tau rad}$ - - - - - - - - (2)

the radiating life time, luminescence life time and quantum efficiency of $Nd^{3+}$ ions in different cost materials are given in table 1. $Nd^{3+}$ exhibit a shorter life time in 6FDA/UVR than in other inorganic hosts mainly due to the luminescent quenching in polymers, while the lifetime of $Nd^{3+}$ ions in $Al_2o_3$ is longer indicating less quenching in this host. However the accuracy of the calculated quantum efficiency by this approach is strongly dependent on the accuracy radiative life time derived by the judd-ofelt theory. Typically an error of a factor 2 is associated with this theory, which explains the quantum efficiency of $Nd^{3+}$ ions larger than unity in Sulphide glass and ZBLAN in table1.

| **Host** | $\tau_{rad}$(ms) | $\tau_{lum}$ | $\eta_{q(\%)}$ |
|---|---|---|---|
| 6-FDA/UVR | 218 | 141 | 64.7 |
| $Al_2o_3$ | 474 | 325 | 68.6 |
| YAG | 259 | 237 | 91 |
| NGAB | 293 | 58 | 19.7 |
| Sulphide Glass | 109 | 110 | 100.9 |
| ZBLAN | 444 | 494 | 111.3 |
| Phosphate Glass | 430 | 190 | 44.2 |
| Lead Silicate Glass | 330 | 290 | 93.0 |

## II. Conclusion

Optical losses in both materials have been studied and compared $Nd^{3+}$ ions complex doped 6-FDA/UVR waveguides have a broad band transmission window starting at 550 nm and extending to around 1100nm. However high loss was observed in this polymer waveguide at the wavelength longer than 1100nm due to the absorption of polymers. $Al_2o_3$: $Nd^{3+}$ waveguides on the other hand, shows a broadband transmission window from visible to telecommunication wavelength.

The experimentally determined luminescence life times show good agreement with the radiative life times calculated from Judd-Ofelt theory.

The optical characterization results indicate that $Nd^{3+}$ ions complex doped 6-FDA/UVR and $Al_2o_3 : Nd^{3+}$ waveguides are well suited for optical amplification and lasing for integrated optical applications

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