Disc Geometry – Based Nd:Glass Laser

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Abstract:

Solid-state laser materials ordinarily consist of a transparent host material doped by active ions that replace some atoms or ions of the original material. These active ions contribute in stimulating laser action by the existence of energy levels relevant to spectra of absorption and emission. Specifically, neodymium glasses, which fluoresce at 1.06µm due to a transition from the $^4F_{3/2}$ to the $^4I_{11/2}$ state in the Nd^{3+} ion, have found interesting applications in the production and amplification of lasers used in laser fusion. The laser material interacts with the field incident on it and is pumped by one or more excitation sources (lamps or diode lasers). The pumping light may be directed towards the laser material from any direction relevant to laser radiation.

The present work deals with the design, construction and characteristics study of solid state laser and Nd:glass, pumped with diode laser array at its end. A maximum power of 1 watt of 808 nm has been utilized to pump the Nd: glass disc of 2mm thickness and 12 mm diameter.

***Keywords: Nd:Glass, Laser, Disc*.**

هندسية القرص لليزر زجاج النديميوم

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المستخلص:

تَتضمّنُ موادُ ليزرِ الحالة الصلبة بشكل عاد من مادّة مضيّفٍ شفّافةٍ مطعمة بالآيوناتِ النشيطةِ التي تَستبدلُ بَعْض الذرّاتِ أو آيوناتِ المادّةِ الأصليةِ ، هذه الآيوناتِ النشيطةِ تُسهمُ بتَحفيز عمل

اللیزرِ بوجودِ مستوى الطاقةِ ذ ي العلاقةَ بأطيافِ الإمتصاصِ والإشعاعِ. بشكل مُحدّد ، زجاج الندميوم، التي تَستشعُّ في 1.06 µm بسبب إنتقال مِنْ $^4F_{3/2}$ إلى حالة $^4I_{11/2}$ في آيون الندميوم +3، وَجدَ إثارة اهتمام تطبيق بالمُنْتَجاتِ ومبالغاتِ الليزرِ يُستَعملانِ لإنْتاج الإنشطارِ. تَتفاعلُ مادّةُ الليزرَ بحقلِ الإشعاعَ عليه ومَضْخُوخةُ بواحد أو مصادرِ إثارةِ أكثرِ (مصابيح أو ليزر دايود). ضوء المضخّةَ قدْ يَكُون على مادّةِ الليزرَ مِنْ أيّ إتّجاه نسبة إلى إشعاعَ الليزرَ. يَتضمّنُ العملُ الحاليُ التصميمُ . دراسة الخصائصَ وبناءَ ليزرِ الحالة الصلبةِ لزجاج الندميوم، ضَخَّ بصَفٍّ دايود ليزر مِنْ نهايتِه. قوَّة قصوى مِنْ 1 واطِ كَانتْ مُستَعْملةَ مِنْ 808 nm أنْ تَضْخَّ دسك الندميوم الزجاجي مِنْ سُمكِ 2 مليمترِ و 12 مليمتر قطرِ.

1-Nd:Glass Laser

Nd: glass is important for laser fusion drivers because it can be produced in large sizes[1].

There is a number of characteristics which distinguish glass from other solid-state laser host materials. Its properties are isotropic. It can be doped at very high concentrations with excellent uniformity, and made in large pieces of diffraction-limited optical quality. In addition, glass lasers have been made, in a variety of shapes and sizes, from fibers, a few micrometers in diameter, to rods 2m long and 7.5cm in diameter, and disks up to 90cm in diameter and 5cm thick [1].

There is a wide variety of Nd-doped laser glasses depending on the composition of the glass network former and the network-modifying ions. Among various laser glasses only silicates and phosphates are commercially available with sufficiently suitable optical and mechanical properties. The Nd: phosphates glasses are generally characterized by a large stimulated emission cross section (σ =3.7-4.5 $\times 10^{-20}$cm^2) and a relatively small nonlinear index (n_2 = 0.91-1.15$\times 10^{-13}$ ESU). Typically, the cross section of a phosphate laser glass is 50% higher than a comparable silicate. The Nd: phosphate glasses have been adopted in large laser systems employed for laser fusion research [1].

Since the advent of lasers, thousands of glasses have been produced to investigate the effects of changes in glass network and network-modifier ions on the spectroscopic and lasing parameters of neodymium. The host glass has an important influence on the ability of the lasing ion to absorb light from the optical pumping source to

store this energy and to release it to amplify the laser beam. Energy storage by the lasing ion is governed by its absorption properties, excited-state lifetimes, and quantum efficiency. For rare-earth laser glasses, the energy-storage capability varies only slightly with the host glass. The rate of energy extraction, on the other hand, is governed by the product of the intensity of the extracted beam and the stimulated-emission cross-section σ of the lasing ions. Both of these factors are strongly influenced by the characteristics of the host glass. Hence, by appropriate choice of host glass, one can produce lasers with wide varying performance [1].

The most common commercial optical glasses are oxide glasses, principally silicates and phosphates, i.e., SiO_2 and P_2O_5 based. Table (1-1) summarizes some important physical and optical properties of commercially available silicate and phosphate glasses. The 1053-nm gain cross sections of available phosphate glass range from 3.0×10^{-20} to $4.2 \times 10^{-20} cm^2$, and are generally larger than the 1064-nm cross sections of silicate glasses. Silicate and phosphate glasses have fluorescent decay times of around 300μs at doping levels of 2×10^{20} Nd atoms/cm^3 [1].

Nonradiative processes account for 50-60% of the excited decay [1].

In high-power lasers of intense radiant fluxes, such as those employed in fusion research, nonlinear contributions to the refractive index and two-photon absorption become critical. It has been shown that those two nonlinear effects are minimized in fluoride glasses such as fluorphosphate and fluorberyllate [1].

Table 1-1: Physical and Optical Properties of Nd-Doped Glasses [1]

Peak Wavelength [nm]	*Q*-246 Silicate (Kigre)	*Q*-88 Phosphate (Kigre)	*LHG*-5 Phosphate (Hoya)	*LHG*-8 Phosphate (Hoye)	*LG*-670 Silicate (Schott)	*LG*-760 Phosphate (Schott)
Peak Wavelength [nm]	1062	1054	1054	1054	1061	1054
Cross Section [X10-20cm2]	2.9	4.0	4.1	4.2	2.7	4.3
Fluorescent Lifetime [μs]	340	330	290	315	330	330
Linewidth FWHM [nm]	27.7	21.9	18.6	20.1	27.8	19.5
Density [g/cm3]	2.55	2.71	2.68	2.83	2.54	2.60
Index of refraction [Nd]	1.568	1.545	1.539	1.528	1.561	1.503
Nonlinear Index n_2[10-13esu]	1.4	1.1	1.28	1.13	1.41	1.04
***dn/dt* (20°-40°C[10-6/°C]**	2.9	-0.5	8.6	-5.3	2.9	-6.8
Thermal Coefficient of Optical Path (20°-40°C[10-6/°C]	48.0	42.7	+4.6	+0.6	8.0	-
Transformation Point [°C]	518	367	455	485	468	-
Thermal Expansion coeff. (20°-40°C)[10-7/°C]	90	104	86	127	92.6	138
Thermal conductivity [W/m°C]	1.30	0.84	1.19	-	1.35	0.67
Specific Heat [J/g°C]	0.93	0.81	0.71	0.75	0.92	0.57
Knoop Hardness	600	418	497	321	497	-
Young's Modulus [kg/mm2]	8570	7123	6910	5109	6249	-
Poisson's Ratio	0.24	0.24	0.237	0.258	0.24	0.27

2-Laser Properties

There are two important differences between glass and crystal lasers. First, the thermal conductivity of glass is considerably lower than that of most crystal hosts. Second, the emission lines of ions in glasses are inherently broader than in crystals. A wider line increases the laser threshold value of amplification. Nevertheless, this broadening has an advantage. A broader line offers the possibility of obtaining and amplifying shorter light pulses, and, in addition, it permits the storage of larger amounts of energy in the amplifying medium for the same linear amplification coefficient. Thus, glass and crystalline lasers complement each other. For continuous or very high repetition-rate operation, crystalline materials provide higher

gain and greater thermal conductivity. Glasses are more suitable for high-energy pulsed operation because of their large size, flexibility in their physical parameters, and the broadened fluorescent line [1].
Unlike many crystals, the concentration of active ions can be very high in glass. The practical limit is determined by the fact that the fluorescence lifetime and, therefore the efficiency of stimulated emission, decreases with higher concentrations. In silicate glass, this decrease becomes noticeable at a percentage of 5% Nd_2O_3 [1].

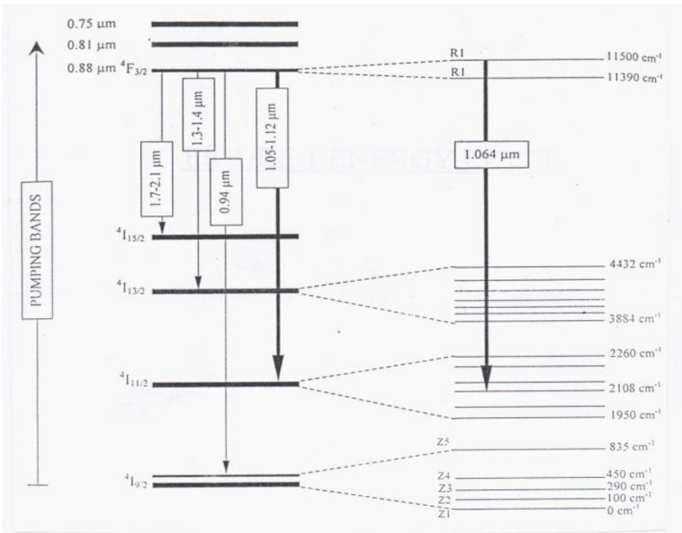


Figure 1-1: Schematic Diagram of the Splitting of Nd^{3+} Energy Levels in Glass Host [2]

Figure (1-1) shows a simplified energy level diagram of Nd: Glass.

Motivations that make Nd^{3+}: Glass lasers one of the most important lasers to be used today are [3]:

1- The absorption spectrum of Nd^{3+} in typical optical extends from ≈350 nm in the ultraviolet to ≈900 nm in the infrared. This is good overlapping in brightness within the pumping source, such as Xe flash lamps.
2- The output wavelength in the vicinity at 1.06 µm is of interest in laser inertial confinement experiments and, although a shorter

wavelength is desirable, leads to reasonable plasma-coupling efficiency.

3- The laser transition of most interest is 1.06 µm and is capable of large energy storage.

4- The stimulated-emission cross section for the Nd^{3+} laser transition is in the intermediate regime, large enough to provide gain in reasonably sized amplifiers, but not so large as to make the problem of amplified spontaneous emission (ASE) severe.

3-Pumping by Diodes

Semiconductor or diode lasers are exceptional in their high electrical/optical efficiency. Therefore, they are of increasing importance for pumping solid-state lasers. The wavelength of the diode laser can be tuned to an absorption band of the laser crystals only slightly above the upper laser. The pumping process efficiency is higher than and simultaneously the thermal load is less than in the case of excitation by lamps [4].

For Disk geometry (active medium), the direction of the pump radiation relative to the laser radiation is mostly parallel.

The advantages of pumping by diode laser are [5]:

- Increased component and system lifetime and reliability is higher in laser diode pumped solid-state lasers as compared to flashlamp based systems. Laser-diode arrays exhibit life times on the order of 10^4 h in CW operation and 10^9 shots in pulsed mode. Flashlamp life is of the order of 10^8 shots, and about 500 h for CW operation.
- Benign operating features. The absence of high-voltage pulses, high temperatures and UV radiation encountered with arc lamps leads to much more benign operating features of laser-diode-pumped systems. Furthermore, a substantial UV content in lamp pumped systems causes material degradation in the pump cavity and in the coolant, which leads to system degradation and contribute to maintenance requirements. Such problems are virtually eliminated with laser-diode-pump source.
- Enabling technology for compact and versatile laser systems. The directionality of the diode output and the small emitting area, as compared to lamp pump sources make it possible to design whole new classes of solid-state lasers, such as end-pumped systems, microchip lasers and fiber lasers. The flexibility of shaping and transferring the output beam from the pump source to the laser

source to the laser medium provides a great opportunity for the invention of new pump configurations and design architectures.

4-Spectroscopic Measurement

The absorption spectrum of the prepared and Nd^{3+} ion doped sample was measured. The integrated absorption spectrum chart that represents the relationship between the wavelength and the absorption coefficient α (λ) was constructed. The wavelength absorption coefficient relationship is

$$\alpha(\lambda) = 2.303\frac{A}{D} \qquad \textbf{(1-1)}$$

Where:

α (λ) is the absorption coefficient
A is the absorbance
D is the thickness of the active medium

Figure (1-2) shows the integrated absorption spectrum for a sample of 2.6 % doping ratio while Figure (1-3) represents the absorption spectrum of the standard sample (ED-2).
The absorption cross-section was calculated from the relationship (1-2)

$$\sigma(\lambda) = \frac{\alpha(\lambda)}{\rho} \qquad \textbf{(1-2)}$$

Where:

***σ(λ)* is the absorption cross-section**
***ρ* is**

While the integrated cross-sectional value $\int\sigma(\lambda)d\lambda$ was calculated by equation (1-3) below

$$\int\sigma(\lambda)d\lambda = \frac{\int\alpha(\lambda)d\lambda}{\rho} \qquad \textbf{(1-3)}$$

Where:

$\int\sigma(\lambda)\,d\lambda$ is the integrated absorption cross-section
$\int\alpha(\lambda)\,d\lambda$ is the integrated absorption coefficient

The oscillator strength F_{ED} was calculated from equation (1-4)

$$F_{ED} = \frac{mc}{\pi e^2 n} \int \sigma(\lambda) d\lambda \qquad \textbf{(1-4)}$$

Where:

F_{ED} is the oscillator strength

c is the light velocity

n refractive index, calculated form equation (1-5) below:

$$n = \left[\frac{4R}{(R+1)^2} - K^2 \right]^{1/2} - \frac{R+1}{R-1} \qquad \textbf{(1-5)}$$

Table 1-2: Spectrum Values for Glass Sample

Thickness d(cm)	Conc. Nd^{+3} Wt%	Absorption Coef. $\alpha(\lambda)(cm^{-1})$	Absorption Cross-section $\sigma(\lambda)*10^{-20}(cm^2)$	$\int_{808}\alpha(\lambda)d\lambda$ cm^{-1}	$\int_{808}\sigma(\lambda)d\lambda$ $*10^{-20}cm^2$	Oscillator Strength (F_{ED})
0.235	2.6	3.038	1.1462	115.9151	43.7365	0.963224

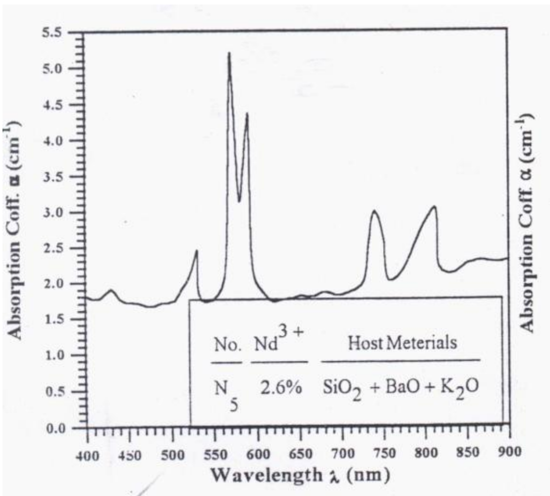


Figure (1-2): The Integrated Absorption Spectrum for a Sample of 2.6% Doping Ratio [2]

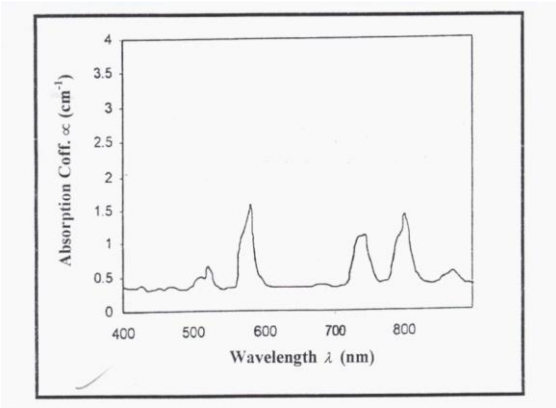


Figure (1-3): The Absorption Spectrum of the Standard Sample (ED-2) [2]

5- Fluorescence Spectrum Measurement

The sample (disc) has been pumped with laser diode with maximum power 1 watt and 808 nm wavelength. The generated fluorescence spectrum signal was detected by a silicon optical detector. An optical filter was installed in front of the detector in order to permit the passage of a narrow band within the range (1060 nm). This was done using a sample holder in order to determine the proper position to detect the floursense signal. This is to avoid the pumping source signal interference where an oscilloscope is used to record the generated signal as is shown in Figure (1-4), while Figure (1-5) shows the laser active medium.

Figure (1-4): Nd: Glass Laser System

Figure (1-5): The Laser Active Medium

Figure (1-6) shows the incident signal on the detector which is the laser signal. In order to ensure that the received signal is a laser signal, not a fluorescence signal emitted by the sample, one of the resonator mirrors was removed leading to attenuation of the received signal at the oscilloscope. When that mirror was returned the laser signal returned as shown in Figure (1-7).

6-Conclusions

1. **A glass sample doped by Nd^{3+} ions at 2.6 % was manufactured as a disc of 2mm thickness and a 12 mm diameter.**
2. **The emitted fluorescence radiation at 1.06µm of the laser medium sample was detected. This signal was close to the standard (ED-2) signal.**
3. **The spectral properties of the sample doped by the ion Nd^{3+} give a clue to the possible use in a solid state laser.**

Getting a Laser signal with Oscillator Strength = 0.963224.

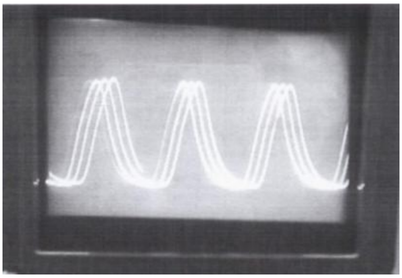
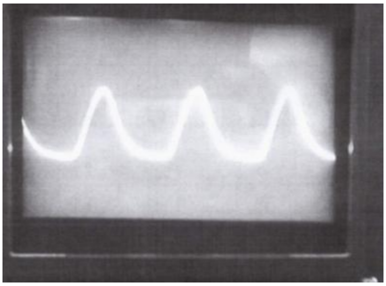


Figure (1-6): Signal of the Laser



Figure(1-7):Signal of the fluorescence

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