Study the Impact of Silica Nanoparticles on the Properties of Several Dyes for the Fabrication of a Random Laser Gain Medium

Noor Y. Khudair*, Mohammed K. Dhahir

Institute of Laser for Postgraduate Studies, University of Baghdad, Baghdad, Iraq
* Email address of the Corresponding Author: Noor.Yasir2101m@ilps.uobaghdad.edu.iq

Abstract: Random laser gain media is synthesized with different types of dye at the same concentration (1×10^{-3} M) as an active material and silicon dioxide NPs (silica SiO_2) as scatter centers through the Sol-Gel technique. The prepared samples are tested with UV–Vis spectroscopy, Fluorescence Spectroscopy, Field Emission Scanning Electron Microscopy (FESEM), and Energy Dispersive X-ray Diffraction (EDX). The end result demonstrates that doped dyes with silica nanoparticles at a concentration of 0.0016 mol/ml have lower absorbance and higher fluorescence spectra than pure dyes. FESEM scans revealed that the morphology of nanocrystalline silica is clusters of nano-sized spherical particles in the range (25-67) nm. It is concluded that the various dyes with SiO_2 as a scattering center can be proposed to build laser media.

Keywords: Random lasers, sol-gel, silica (SiO_2), dyes, nanoparticles.

1. Introduction

Since the introduction of the first laser in 1960, the manufacturing of high-efficiency laser systems has been one of the most fundamental difficulties in laser physics [1–2]. Lawandy et al. demonstrated in the early 1990s a stimulated emission from laser dye containing microparticles, hence the phrase "random laser" [3], which led to several theoretical [4–5] and experimental [6–7] studies on the amplification of light in diffusive media. The mechanisms of random lasers (RLs) are based on multiple light scattering. In random lasers, as opposed to two highly reflecting mirrors in conventional lasers, the resonant cavity is constructed by repeated multiple scattering. In an active medium with a disordered distribution of scattering particles or domains, fluorescence photons may be multi-scattered thousands of times in random directions before leaving the medium. When scattering photons propagate via a narrow circuit, recurrent multiple scattering may either produce incoherent or coherent feedback [8]. RL has several advantages such as small size, low cost, flexible shape, and many others; It has several applications in integrated optics [9], temperature...
sensing [10], document encoding, material labeling, high-density optical data storage [11], tumor diagnostics [12-13], liquid crystal display [14], and liquid flow monitoring [15]. Many random laser mediums have been widely demonstrated, including ZnO powders [16-17], Rare-earth ion-doped crystalline powders [18-19], conjugated polymers [20-21], dye-doped liquid crystals [22-23], dye-doped polymer films enhanced by silver or gold nanoparticles [24-25], a few biological issues doped with laser dye [26-27], and organic dye solutions doped with dielectric scatters [3-28].

Laser dyes are one of the organic luminescent materials with high molecular weight that can be used as an active medium because they are composed of carbon atom chains connected alternately by a single and double band called chromfore [29], while many tiny particles such as TiO₂ particles, zinc oxide (ZnO) [30], silica (SiO₂), tungsten oxide (WO₃), alumina (Al₂O₃) [31], and others can be used as scatter.

The goal of this work is to create random laser gain media by doping silica nanoparticles (SiO₂) with different types of dye (Rhodamine B, Rhodamine 101, Crystal Violet, and Fluorescein) at the same concentrations (1×10⁻³ M) in the Sol-Gel method and studying its characterization features.

2. Experimental work

The fabrication of random laser gain media through the sol-gel technique includes mixing 3 ml of ethanol as a solvent (purity 99.9%), 3 ml of tetraethylorthosilicate (Glentham Life Sciences Ltd., 99% purity) as a precursor material, 3 ml of deionized water (pH = 1 by adding 0.15 ml of HCl as a catalyst), and 0.6 ml (0.0001g dissolved in ethanol) from Rhodamine 610 and Rhodamine 640 dyes (supplied by Lambda Physik), Crystal Violet dye (supplied by Avonchem Limited) and Fluorescein dye (supplied by Sinopharm Chemical Reagent) to make all the prepared samples at a concentration of (1×10⁻³ M).

The mixtures are stirred for 15 minutes at 100°C on the magnetic stirrer, and then the samples are aged and dried at room temperature for around 4 days in closed glass vials to produce four disk samples of random laser gain media. Energy Dispersive X-ray Diffraction (EDX) with XFlash 6L10, Field Emission Scanning Electron Microscopy (FE-SEM) with Inspect TM F50, UV-Visible spectrometry with a Shimadzu UV-VIS 1800 spectrophotometer, and F96 Shanghai Leng Guang Fluorescence Spectrophotometer were used to analyze the structural and optical characteristics of random laser gain media in the Sol-Gel technique.

3. Results and discussion

3.1 Morphological properties

As shown in Fig.1, SEM images indicate clusters of spherical, bright spots (circles and inset picture) that correspond to silicon oxide (SiO₂) nanoparticles with a mean particle size of around (25–67) nm for all prepared samples. By exhibiting peaks corresponding to the energy levels for each element in the test, EDX was used to confirm the structural purity of the samples.

As shown in Fig.2, all of the samples contain Si as the highest peak in the spectrum, indicating that it is the most concentrated element; the presence of an O peak also confirms the stoichiometry of the silica NPs compound. The other peaks reflect the constituent elements of the dyes in the samples.

3.2 Optical properties

Using UV-Vis spectroscopy, the optical characteristics of the samples were determined. Fig.3 displays the absorption spectra of pure and doped dyes (Rh 101, Rh B, C.V., Fluorescein) with silica at the same concentration (1×10⁻³ M), where the absorption spectra moved to a longer wavelength in the visible region (red shift) after it was doped with SiO₂. This indicates the aggregation of nanoparticles in the dye solution [32], resulting in a shift in wavelengths. While Fig.4 shows the optical transmission spectra of pure and silica-doped dyes, the absorbance spectra for all samples exhibit the opposite pattern.
Fig. 1: SEM image of dyes (a) Rh 101, (b) Rh B, (c) C.V, (d) Fluorescein doped with SiO$_2$ NPs.

Fig. 2: EDX results of dyes (a) Rh 101, (b) Rh B, (c) C.V, (d) Fluorescein doped with SiO$_2$ NPs.
Fig. 3 Optical absorbance spectra of pure and doped dyes at the same concentration with SiO$_2$ for (a) Rh 101 (b) Rh B (c) C.V (d) Fluorescein.
Fig. 4: Optical transmittance spectra of pure and doped dyes at the same concentration with SiO$_2$ for (a) Rh 101 (b) Rh B (c) C.V. (d) Fluorescein. [This is what the results revealed, and they are presented as is].

Fluorescence spectra were acquired using an F96 Shanghai Leng Guang Fluorescence Spectrophotometer. Fig. 5 displays the fluorescence spectra of pure and doped dyes (Rh 101, Rh B, C.V., Fluorescein) with silica at the same concentration ($1\times10^{-3}$ M), where the fluorescence spectra became higher after it was doped with SiO$_2$ with a concentration of 0.0016 mol/ml since nanoparticles can exhibit unique optical and electronic properties that are not present in bulk materials, which means that they can absorb light energy and transfer it to the host material, leading to higher fluorescence.
Fig. 5: Optical fluorescence spectra of pure and doped dyes at the same concentration with SiO$_2$ for (a) Rh 101 (b) Rh B (c) C.V (d) Fluorescein.

4. Conclusion

Using the sol-gel process, several dyes with SiO$_2$ as a scatter are successfully used to create random laser gain media. FESEM images show that the SiO$_2$ particles generated in the entire sample are in the nano range (100 nm), EDX demonstrates that Si is the most prevalent element in every sample, UV-Vis spectra demonstrate that all pure dyes have a higher absorbance than when they are doped, and the Fluorescence Spectrophotometer demonstrates that the fluorescence spectra became higher after it was doped with SiO$_2$ in all samples. [The proposed opinion will be applied to future studies].
References


دراسات تأثير جسيمات السليكا النانوية على خصائص عدة صبغات لتصنيع وسط كسب ليزر عشوائي

نوير ياسر خضير*, محمد كريم ظاهر

معهد الليزر للدراسات العليا، جامعة بغداد، بغداد، العراق

البريد الإلكتروني للباحث: Noor.Yasir2101m@ilps.uobaghdad.edu.iq

الخلاصة: تم تصنيع وسائل كسب الليزر العشوائي من أنواع مختلفة من الصبغات كمادة مضيفة نشطة وجسيمات سيليكات أوتسيد السيليكون النانوية (السيلة) SiO2 كمكراك تشتت من خلال تقنية السول- جل. تم فحص العينات المعدة عن طريق استخدام التحليل الطيفي للأشعة المرئية وفق البنفسجية، التحليل الطيفي العلوي، طيف المجهر الإلكتروني لمسح العينات المبدئي (EDX) و Equip. و طيف حيود الأشعة السينية المشتتة للطاقة (FESEM). أظهرت النتائج النهائية أن الصبغات المشتتة بجسيمات SiO2 تركز فلوراً أعلى في الحزم من الصبغات النانوية. تم الكشف عن 0.0016 mol/ml لحالة وسيلة مجدية للأشعة-TypeLiزرية. FESEM

* البريد الإلكتروني للباحث: Noor.Yasir2101m@ilps.uobaghdad.edu.iq

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