Optical Limiting Properties of Nano-composite Gold Nanoparticles / Epoxy Resin

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ABSTRACT:
In this paper, We prepared nanoparticles using the Turkevich process. The characterization of gold nanoparticles is carried out using a Scanning Electron Microscope (SEM). Linear optical properties studied by UV-visible Spectroscopy. Investigation of the optical limiting properties (OL) of nanocomposite (AuNPs / Epoxy resin) at different thicknesses (2.5, 9, 10.5, 14.3, 20.5, and 34) µm is performed. The threshold and optical clamping were calculated from optical limiting operation implemented by the Z-scan technique using CW Nd: YAG laser at (532 nm). The samples showed low optical limiting thresholds, which can be demonstrated by the strong absorption of the two photons in these samples. The nanocomposite displays the lowest optical limiting threshold (66 mW) at a thickness (2.5) µm. We notice that the nonlinear light-induced absorption results in an optical limited.

1. Introduction
Laser development characterized the great change in science and technology. This led to a wide range of applications in the fields of research, industry, medicine, and military [1]. Continuous-wave lasers (CW) at power levels ranging from µW to kW have been broadly used in different applications. That opens a way to a varied investigation of materials and devices for the safeguard of sensors and human eyes. Particularly, from intense optical beams which have generated considerable interest in the development of optical limiting materials [2]. Optical limiting refers to a reduction in the optical transmittance of an incident light intensity material [3].
The study of optical limiting with metallic nanoparticles attracted a large amount of attention because of its increased request for protection from the danger of a high power laser [4].

The nanocomposite has interesting optical nonlinear performance compared with bulk materials. For example, optical nonlinearity and optical limiting effects (OL) of nanocomposite [5].

The optical limiter is the one that shows the reduced transmittance as a function of beam density or intensity. An ideal optical limiter displays a linear transmission below a limiting threshold value. Above that, the output is clamped to a constant value that protects the sensors [6]. Figure (1) shows the working principle of an ideal optical power limiter.

![Figure (1) Schematic diagram of an ideal optical limiter.](image)

In this paper, the optical limiting tests for various thicknesses for Nano-composite of gold nanoparticles (AuNPs) with epoxy resin with an aperture pinhole of (1) mm. Nd: YAG laser was used in this experiment at (532) nm of wavelength. The input power was used within (50-90) mW range.

The application of nanocomposite is shown to develop optical limiters at low thresholds. Depending on the aperture size, the threshold value, and the distance between the sample and the aperture makes it suitable for optimizing the optical limiting threshold intensity [7].
The corresponding output power is calculated at different laser input power. The far-field profile shows an intensity variation, which is reported through the aperture when the laser power has changed [8].

2- Experimental methods:

2.1 Materials:

Gold nanoparticles (AuNPs) is prepared using the Turkevich process [9]. The theory of this process includes the reduction of gold ions (Au$_3$) to gold atoms (Au$_0$) in the presence of reducing factors such as Trisodium citrate.

The chloroauric acid (HAuCl$_4$) solution was heated using a magnetic stirring after adding deionized water. When the (HAuCl$_4$) solution reaches the boiling point, a particular amount of (Na$_3$Ct) solution injection into the HAuCl$_4$ solution.

The synthesis was achieved when the suspension color no longer changed, and gold nanoparticles reached ruby red. The AuNPs were in concentration (0.05) mg/ml and has (7-8) nm particle size [10].

The polymer, which was used for nanocomposite, was Epoxy resin. It is a liquid with low viscosity that solidifies at room temperature, colorless, humid, and chemical resistant. Epoxy consists of two elements, the first of which is pointed to as the base (resin) as the letter (A) and the second as the hardener (B). Epoxy resin converts to the solid-state by applying a ratio (A: B) (2:1) at room temperature [11].

2.2 Nano-composite samples of gold nanoparticles/epoxy resin preparation:

To prepare the nanocomposite of gold nanoparticles doped with epoxy, we mix (10 ml) of type A epoxy resin with (5) ml of type B epoxy
harder. Subsequently, we add (5) ml of (AuNPs) and put the mixture on a magnetic stirrer for (5) min. After homogenization, the mixture was modified into a glass slide set with a spin coater [12]. The quantity increased each time (4, 6, 8, 10, 12, and 14) drops for (90) seconds and at speeds of (200) rpm. Then, the samples were left at room temperature to dry for two days. After that, the thickness for every sample was then calculated by the thickness measuring device. By calculating the average thickness of the glass samples without the mixture and with the mixture, obtaining the thickness of each sample is performed by measuring the difference between them.

3. RESULTS AND DISCUSSION:
3.1 Morphology of shape and size of Au nanoparticles (SEM)

Using scanning electron microscopy, details were obtained of the sample surface morphology of the epoxy and the particle size of the Au-NPs [13].

SEM imaging demonstrated that the initially formed of samples suffered from a wide distribution in size (figure 2). This is not surprising in light of the mixture's heterogeneity. The cross-section of SEM images displays a homogeneous form of the samples. The images show samples of gold nanoparticles and epoxy resin with a magnification power of (200) nm. With a surface topography as shown in table (1) and the sample shows the strong dispersion. The Image indicates a particle size distribution in the average (26,12) mm diameter for AuNPs and epoxy resin, respectively.
Figure (2) SEM image for samples in magnification of 200 nm for (a) AuNPs (b) epoxy resin.

Table (1) displays the results of SEM indicates a particle size distribution for gold nanoparticles and epoxy resin polymer.

Table.1: SEM results of AuNPs and epoxy resin.

| Sample       | Max. Diameter | Min. Diameter | Average Diameter |
|--------------|---------------|---------------|-----------------|
| AuNPs        | 36.8          | 16.6          | 26.74           |
| Epoxy resin  | 14.14         | 11.62         | 12.88           |

3.1 UV-Visible Spectroscopy.
Figures (3 and 4) show the UV-vis absorption spectrum of the colloids gold nanoparticles and epoxy resin polymer, respectively. It can be observed, from the curve in the figure (3), that the AuNPs have a typical
surface absorption of plasmon (SPA) peak at about (524) nm in the visible region. Whereas the highest absorption of pure epoxy resin is at (209) nm in the ultraviolet spectrum region [14], as clearly appear in figure (4). The absorption point of (0.6, 3.6) for AuNPs and epoxy resin, respectively, as shown in figures (3 and 4).

Figure (3) The absorption spectrum of the gold nanoparticles sample.

Figure (4) The absorption spectrum of epoxy resin polymer.
From the absorption spectrum in figures (3 and 4), it is possible to obtain some linear optical properties of the samples as shown in table (2).

### Table 2: Linear optical properties of Au-NPs and epoxy resin.

| Sample       | Wavelength (nm) | Energy gap $E_g$ (eV) | Refractive index $n_0$ | Linear absorption coefficient $\alpha^0$ (cm$^{-1}$) | Extinction coefficient $k_0$ |
|--------------|-----------------|-----------------------|------------------------|------------------------------------------------------|-----------------------------|
| AuNPs        | 524             | 5.1                   | 1.89                   | 2.5                                                  | $1.9 \times 10^{-6}$        |
| Epoxy resin  | 209             | 6.5                   | 0.87                   | 8.8                                                  | $1.2 \times 10^{-8}$        |

### 3.3 Optical limiting for nanocomposite

The optical limit behavior was examined by the Z-scan technique. This is performed using CW Nd: YAG laser operating at 532 nm wavelength, as presented in figure (5), for prepared nanocomposite (AuNPs/Epoxy) at different thicknesses about (2.5, 9, 10.5, 14.3, 20.5 and 34) µm. The sample was put in the focus of the laser beam and the light intensities transmitted through the sample were measured for different input intensities. Figure (5) shows optical limiting and clamping curves as an incident power varying from (50-90) mW for various nanocomposite thicknesses. The optical clamping was analyzed by deriving the line from the saturation point where it occurred [15].

From figure (5), one can notice that the output power of laser changes with the input power. The laser beam output is becoming nonlinear when the incident beam power reaches (50) mW, and the incident power...
does not exceed (60) mW. For larger input power (excluding the 60 mW), the input power for all samples varies linearly with output power. It is observed that the output power was raised with increasing input power until the limiting threshold at which the output power is somehow fixed [16].

The optical limiting threshold and clamping for nano-composites are given in table (3). It indicates that the limitation threshold values are directly proportional to the sample thickness from nanocomposite optical limiting data. The reduction in linear transmission below a threshold and the optical clamping with increased thicknesses is observed. Moreover, because of the higher thickness sample has more phase-participating molecules and is thermally irritated to excited states, therefore, better limiting and clamping are observed.
Figure (5) Optical limiter for Nano-composite of AuNPs with epoxy resin at different thicknesses.

Nano-composite (AuNPs / Epoxy resin) threshold values and optical clamping at various thicknesses are described in table (3):
Table 3: Threshold power for Nano-composite of AuNPs with epoxy resin at different thicknesses.

| Thicknesses (µm) | Threshold power (mW) | Optical clamping (mW) |
|------------------|----------------------|-----------------------|
| 2.5              | 66                   | 6.3                   |
| 9                | 69                   | 6.4                   |
| 10.5             | 70                   | 5.9                   |
| 14.3             | 70                   | 6.5                   |
| 20.5             | 71                   | 6.6                   |
| 34               | 72                   | 4.9                   |

4. Conclusions

The objective of this research is to study the optical limiting properties of nanocomposite, which consists of gold nanoparticles and polymer epoxy resin at different thicknesses. This is achieved by the Z-scan technique using CW Nd: YAG laser at (532) nm, changing input power in the range of (50-90) mW.

With changes in the experimental design, for example, the aperture size and position behind the sample, the limiting threshold can be developed.

It was observed that the larger-thickness (34) µm of nanocomposite possesses relatively the largest optical limiting properties that mean the higher threshold power and less optical clamping. The results of optical power limiting indicate a good optical limit of CW laser in this work. A maximum optical limit threshold and clamping of 72 mW and 6.6 mW was observed.
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