

The Effect of Electromagnetic Radiation “Laser” on Matter Properties

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Abstract:

The interactions between light and matter play a fundamental role in many fields of science, by rearranging the smallest cosmic particles that carry the information code, leading to important applications in spectroscopy, sensing, quantum information processing, and lasers. In most of these applications, light is viewed in terms of electromagnetic plane waves that propagate at the speed of light in a vacuum. Electromagnetic radiation or electromagnetic waves is a form of energy emitted and absorbed by charged particles, which exhibit wave-like behavior as they travel through space. Electromagnetic radiation has an electric field and a magnetic one, equal in intensity, and each oscillates in phase perpendicular to the other and perpendicular to the direction of energy and wave propagation, as electromagnetic radiation propagates in a vacuum at the speed of light. The effects of electromagnetic radiation on living systems (and many chemical systems under standard temperature and pressure conditions) depend on both the strength and frequency of the radiation. The effects of low-frequency electromagnetic radiation down to the visible light frequency on ordinary cells and materials are limited by heat and heating and therefore depend on the strength of the radiation. In contrast to higher frequency radiation such as UV and higher, the damage to chemicals and living cells is much greater than simple heating due to the ability of single photons at such frequencies to chemically destroy individual molecules. Since the invention of the laser until the present day, researchers and scientists have been searching for the effect of the laser on the

properties of the materials it interacts with. Most of the recent inventions, including lasers and their interaction with various materials, have given wide scope for industrial, medical and other applications. In this research, the interaction of the laser beam with the materials and its effect on its optical and microscopic properties is studied. Three different wavelengths (green, blue, and red) were chosen, with lengths (532 and 405,650) nm. As for the materials used, they are different minerals and salts in the solid state as powder and pieces of different sizes and shapes. The effect of lasers on matter is studied through the use of optical spectrometers and optical microscopes. The results of the microscope showed the effect of the laser on the properties of the metal surface by making scratches, while the results of the infrared spectrum showed the structural properties of the materials, in addition to the effect of the laser on showing the spectrum of the induced fluorescence, which is a special fingerprint for each material.

1-1 Introduction

The physical processes in laser material interaction are important for understanding the capabilities and limitations of laser effect processes. Light is an electromagnetic wave or photon. In the classical sense, electromagnetic radiation is considered to be wave-like, Laser radiation is an electromagnetic (EM) radiation and can be represented as an electric vector field and magnetic field, Figure (1.1).[1]

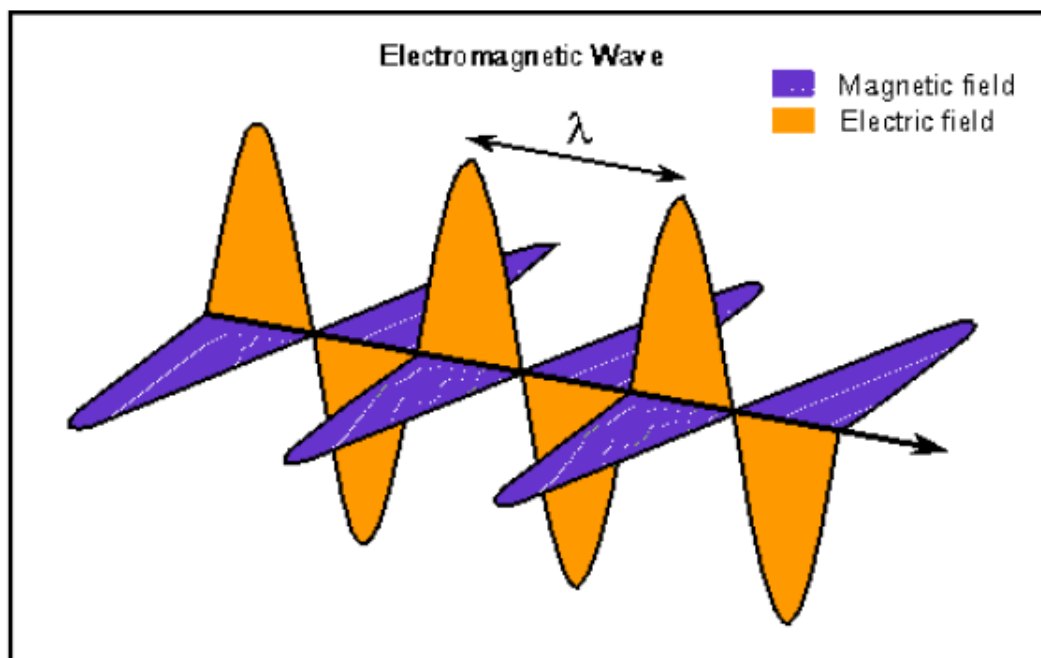


Figure (1.1) The electric and magnetic field vectors of EM radiation.

The spectrum consists of radiation such as gamma rays, x-rays, ultraviolet, visible, infrared and radio. Visible light lies within a very narrow region of the spectrum, with wavelengths ranging between about $0.4\mu\text{m}$ ($4 \times 10^{-7} \text{ m}$) for violet and $0.7\mu\text{m}$ for red color as in figure (1.2).[2]

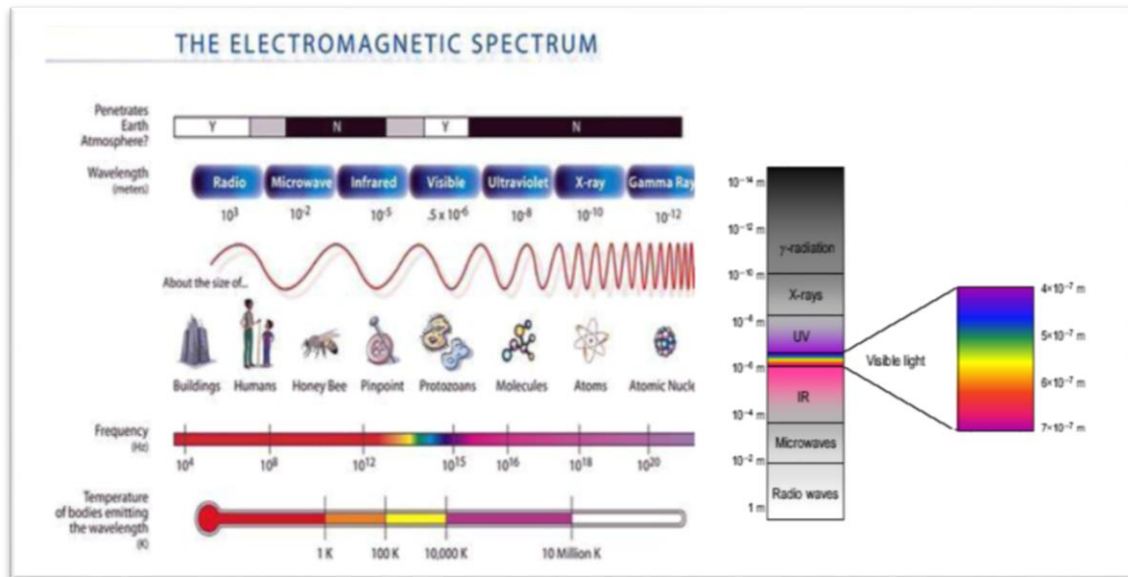


Figure (1.2) electromagnetic spectrum

1-2 Theory

All electromagnetic radiation traverses a vacuum at the same velocity, that of light—namely, 3×10^8 m/s (186,000 miles/s). This velocity, c , is related to the electric permittivity of a vacuum and the magnetic permeability of a vacuum through [3]:

$$c = 1 / (\epsilon_0 \mu_0)^{1/2} \dots\dots\dots (1)$$

Energy of photon is

$$E = hf = h\nu = hc/\lambda \dots\dots\dots (2)$$

h : Planck's constant = 6.63×10^{-34} J-s. When EM wave radiation (laser beam) strikes a surface (air/solid interface) it undergoes a reflection and transmission. Some radiation is transmitted, some reflected and, some absorbed. As it passes through a new medium it is absorbed according to Beer Lambert's law[4]:

$$I = I_0 e^{-\mu \cdot z} \dots\dots\dots (3)$$

where, the absorption coefficient μ , depends on the medium, wavelength of the radiation and the intensity I , temperature, and the plasma formation above the target. When EM wave passes through a small elastically bound charged particle, the particle will be set in motion by the electric force from the electric field, E . The force is very small and is incapable of vibrating an atomic nucleus. This process of photons being absorbed by electrons is known as the "Inverse Bremsstrahlung Effect". Bremsstrahlung effect is the emission of photons from excited electrons. As the electron vibrates it will either reradiate in all directions or be restrained by the lattice phonon[5].

1-3 Light Interactions with matter:

When light proceeds from one medium into another (e.g., from air into a solid substance), several things happen. Some of the light radiation may be transmitted through the medium, some will be absorbed, and some will be reflected at the interface between the two media , figure (1.3)[6]. The intensity I_0 of the beam incident to the surface of the solid medium must equal the sum of the intensities of the transmitted, absorbed, and reflected beams, denoted as I_T , I_A , and I_R respectively, or:

$$I_0 = I_T + I_A + I_R \dots\dots\dots (4)$$

$T = I_T / I_0$ Transmissivity.....(5)

$A = I_A / I_0$ Absorptivity.....(6)

$R = I_R / I_0$ Reflectivity.....(7)

$T \sim 1$: Transparent

$T \sim 0$: Opaque

$T + A + R = 1$(8)

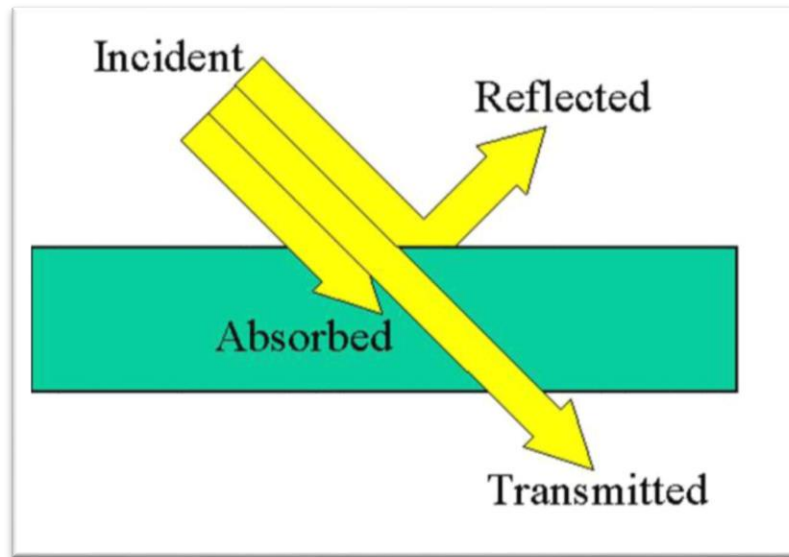


Figure (1.3) light interaction with matter process

1-4 Optical Properties of metals [7]:

1. Metals are opaque because the incident radiation having frequencies within the visible range excites electrons into unoccupied energy states above the Fermi energy
2. Total absorption is within a very thin outer layer, usually less than $0.1 \mu\text{m}$ thus only metallic films thinner than $0.1 \mu\text{m}$ are capable of transmitting visible light.
3. In fact, metals are opaque to all electromagnetic radiation on the low end of the frequency spectrum, from radio waves, through infrared, the visible, and into about the middle of the ultraviolet radiation.
4. Metals are transparent to high-frequency (x- and γ -ray) radiation.
5. All frequencies of visible light are absorbed by metals because of the continuously available empty electron states, which permit electron transitions.
6. Most of the absorbed radiation is reemitted from the surface in the form of visible light of the same wavelength, which appears as reflected light.
7. Aluminum and silver are two metals that exhibit this reflective behavior.
8. Copper and gold appear red-orange and yellow, respectively, because some of the energy associated with light photons having short wavelengths is not reemitted as visible light.

As demonstrated in figure (1.4) .

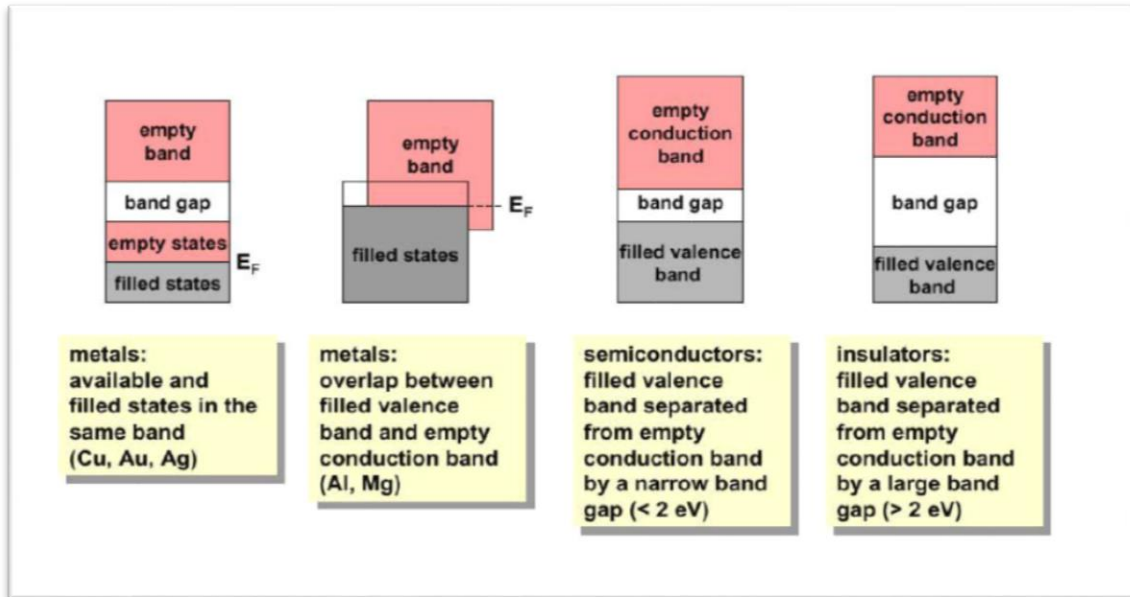


Figure (1.4) material properties

1-5 Electron Transitions:

The absorption and emission of electromagnetic radiation may involve electron transitions from one energy state to another. When a photon, or packet of light energy, is absorbed by an atom, the atom gains the energy of the photon, and one of the atom's electrons may jump to a higher energy level[8]. The atom is then said to be excited. When an electron of an excited atom falls to a lower energy level, the atom may emit the electron's excess energy in the form of a photon. The energy levels, or orbitals, of the atoms shown in figure (1.5) have been greatly simplified to illustrate these absorption and emission processes[9].

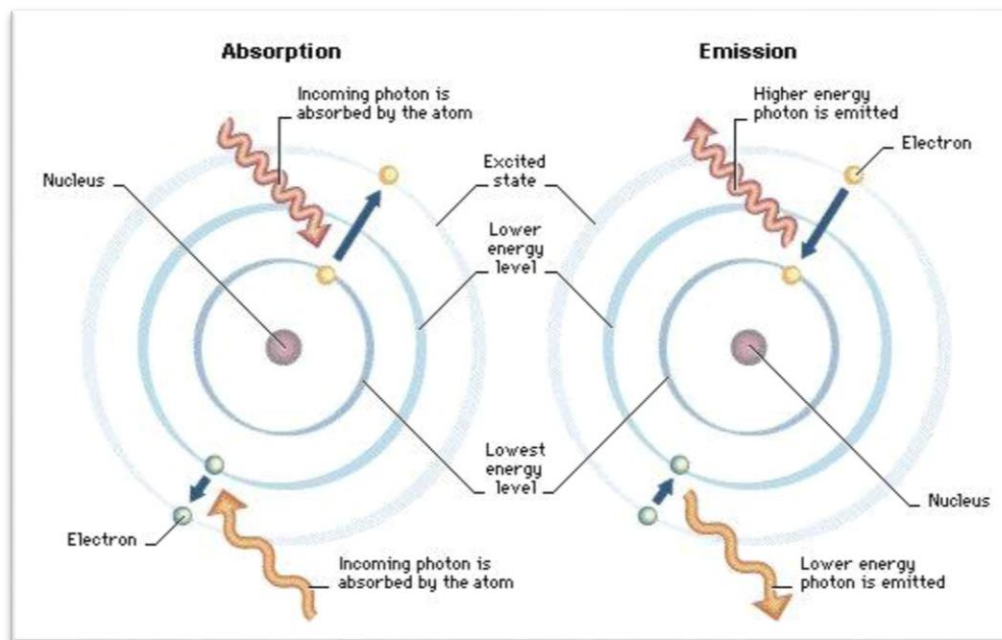


Figure (1.5) absorption and emission processes.

1-6 Optical applications:

Light interacts with a material in many ways, depending on the material, its crystal-/micro-structure, and also on the characteristics of incident light, there are many phenomena occurs, which are known as optical phenomena[10]. These include:

- 1- luminescence
- 2- lasers
- 3- thermal emission
- 4- photo-conductivity
- 5- optical fibers

All these find quite many applications in technology for everyday life.

1-6-1 Luminescence

It is the process where a material absorbs energy and then immediately emits visible or near-visible radiation. It consists of electron excitation and then dropping down to lower energy states. Visible light is emitted when it falls back to a lower energy state if $1.8 \text{ eV} < h\nu < 3.1 \text{ eV}$.

If the reemission of radiation occurs within 10^{-8} sec after excitation, the luminescence is called fluorescence, and if it takes longer than 10^{-8} sec, it is known as phosphorescence[11-12].

Special materials called phosphors have the capability of absorbing high-energy radiation and spontaneously emitting lower-energy radiation. Ex.: some sulfides, oxides, tungstates, and few organic materials. Ordinarily, pure materials do not display these phenomena, and to induce them, impurities in controlled concentrations must be added.

The intensity of luminescence is given as[13]:

$$I = I_0 \exp - t\tau \dots\dots\dots(9)$$

where I_0 – initial intensity of luminescence,

I – fraction of luminescence after time, t ,

τ - relaxation time, constant for a material.

Luminescence process is classified based on the energy source for electron excitation as photo-luminescence, cathode-luminescence, and electro-luminescence[14].

1-6-2 Lasers:

Laser is an acronym for **light amplification by stimulated emission of radiation**. It is in fact special application of luminescence. Unlike most radiation processes, such as luminescence, which produce incoherent light, the light produced by laser emission is coherent[15]. All of the light emission we have mentioned so far is spontaneous. It happened just due to randomly occurring natural effects. Stimulated emission refers to electron transitions that are encouraged by the presence of other photons. Einstein showed that an incident photon with $E \geq E_g$ was equally likely to cause stimulated emission of light as to be absorbed. The emitted light has the same energy and phase as the incident light (= coherent), figure (1.6)[16]. In table (1) characterization and application of several types of lasers.

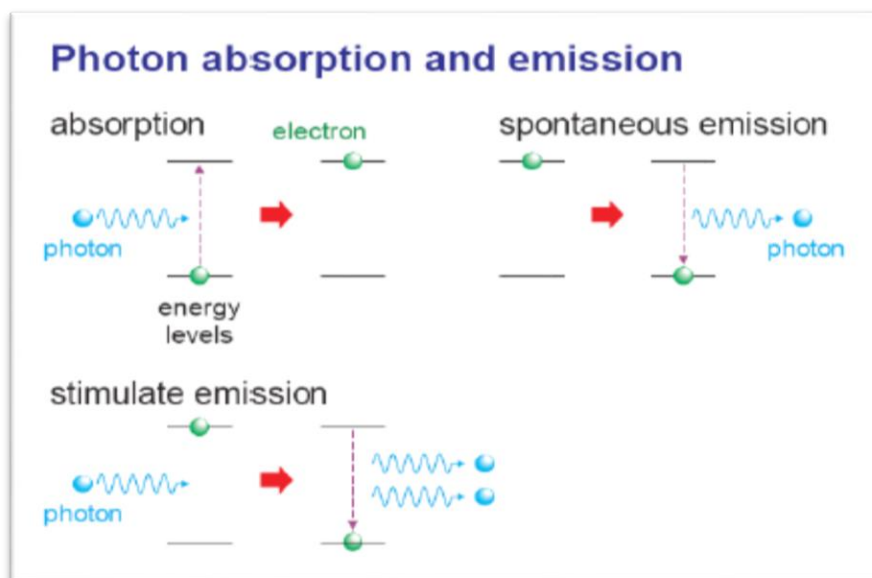


Figure (1.6) Photon absorption and emission

Table (1) characterization and application of several types of lasers

<i>Laser</i>	<i>Type</i>	<i>Common Wavelengths (μm)</i>	<i>Max. Output Power (W)^a</i>	<i>Applications</i>
He-Ne	Gas	0.6328, 1.15, 3.39	0.0005–0.05 (CW)	Line-of sight communications, recording/ playback of holograms
CO ₂	Gas	9.6, 10.6	500–15,000 (CW)	Heat treating, welding, cutting, scribing, marking
Argon	Gas ion	0.488, 0.5145	0.005–20 (CW)	Surgery, distance measurements, holography
HeCd	Metal vapor	0.441, 0.325	0.05–0.1	Light shows, spectroscopy
Dye	Liquid	0.38–1.0	0.01 (CW) 1×10^6 (P)	Spectroscopy, pollution detection
Ruby	Solid state	0.694	(P)	Pulsed holography, hole piercing
Nd-YAG	Solid state	1.06	1000 (CW) 2×10^8 (P)	Welding, hole piercing, cutting
Nd-Glass	Solid state	1.06	5×10^{14} (P)	Pulse welding, hole piercing
Diode	Semiconductor	0.33–40	0.6 (CW) 100 (P)	Bar-code reading, CDs and DVDs, optical communications

^a "CW" denotes continuous; "P" denotes pulsed.

1-7 Fluorescence Terminology

Fluorescence is a mechanism of photon emission that occurs from electronic excited states during molecular relaxation. These photonic processes include transitions of polyatomic fluorescent molecules between electronic and vibrational states (fluorophores). Figure (1.7) provides a convenient representation of the configuration of the excited state and related transitions[17].

An external light source of a certain wavelength is used in fluorescence imaging to excite a target fluorescent molecule. The fluorescent molecule emits a photon of lower energy at a higher wavelength upon excitation. A highly sensitive CCD camera system will subsequently detect this emitted photon[18].

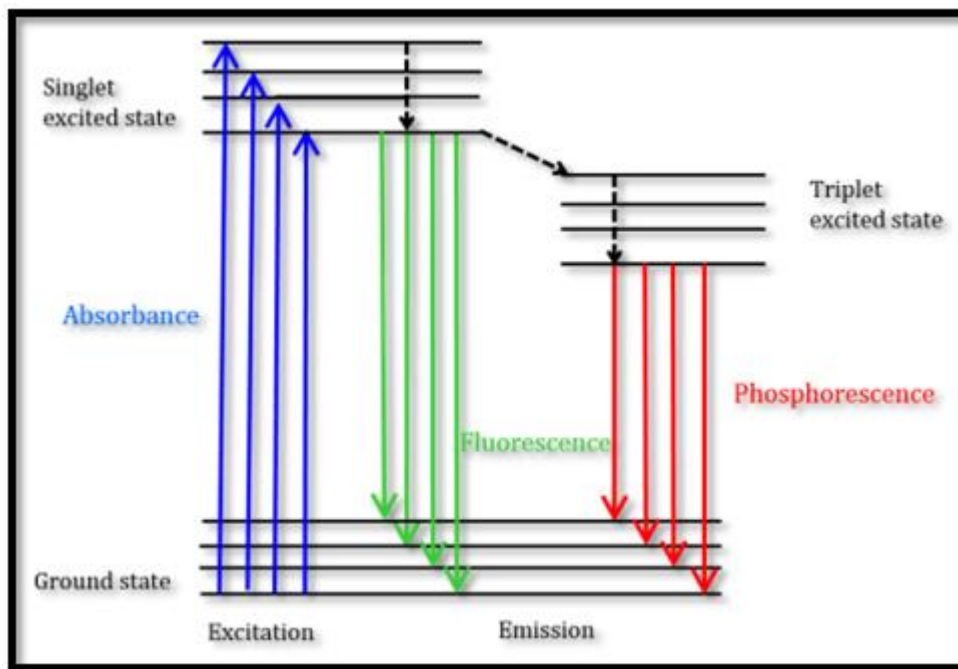


Figure (1.7) Transitions giving rise to absorption and fluorescence emission spectra

1-8 What is Laser Induced Fluorescence

Laser Induced Fluorescence (LIF) is an optical spectroscopic technique where a sample is excited with a laser, and the fluorescence emitted by the sample is subsequently captured by a photo-detector[19]. LIF can be understood as a class of fluorescence spectroscopy where the usual lamp excitation is replaced by a laser source. Whilst lasers are now routinely used as excitation sources in photoluminescence spectrometers, Laser Induced Fluorescence was not originally developed for a commercial instrument but as a standalone laser spectroscopy technique, figure.(1.8)[20]

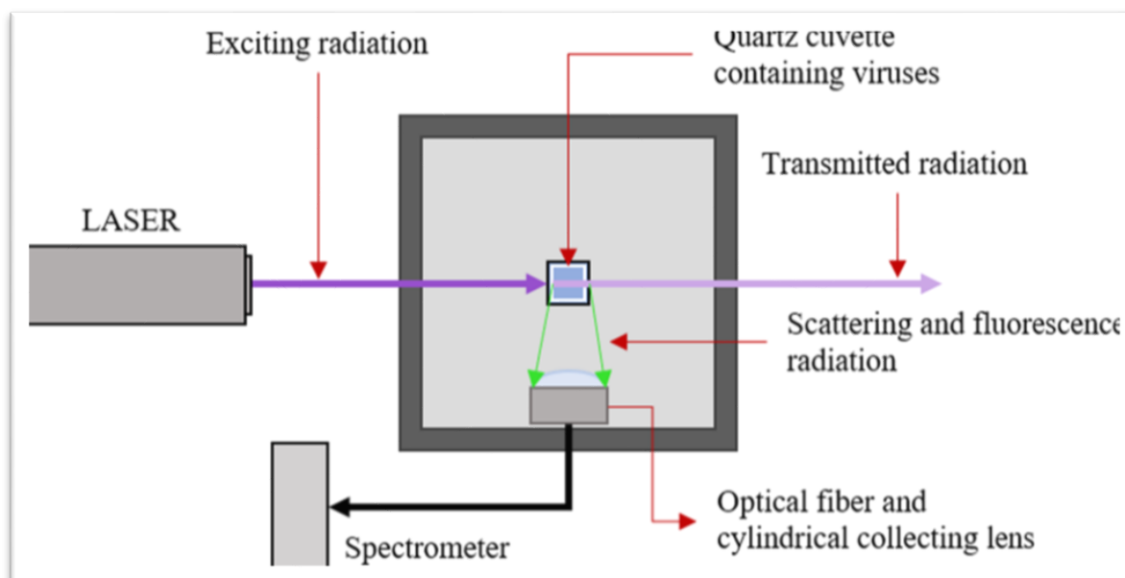


Figure (1.8) Experimental apparatus scheme.

Method, materials and devices

In this research, which study interaction electromagnetic radiation beam (laser) with matter, diode lasers of different wavelengths were used in the visible region, and the samples were in the form of powdered minerals and in the form of pieces of different sizes and shapes. To analyze the results, a sensitive balance with high sensitivity (10^{-4}) was used, as well as different spectrometers to detect the influence of different materials by laser and to study the structural properties, reflecting and transmission microscopes were also used to study the surface properties, in addition single-mode optical fibers, different magnetic holders and bases, and an optical table are used.

2-1 Laser devices

Three diode lasers were used with (405, 532, 650) nm wavelengths.as in figure (2.1).



Figure (2.1) laser diodes

2-2 samples

The samples used to study the effect of the laser are metals and powders of different sizes and weights (copper sulphate, cobalt, aluminum welding powder) and 3 metals (silver, copper and pure gold) were weighed in the solid state in the form of pieces of compressed discs, each weighing (copper = 1 g), (silver = 3 g), (gold = 1 g).as shown in figure (2.2)



Figure (2.2) metal and powder samples

2-3 sensitive balance

In this sensitive scale device, the materials are weighed before using in an experiment, consisting of a weighing room that is isolated from air by glass and a digital screen with high sensitivity (10^{-4}) as demonstrated in figure (2.3).

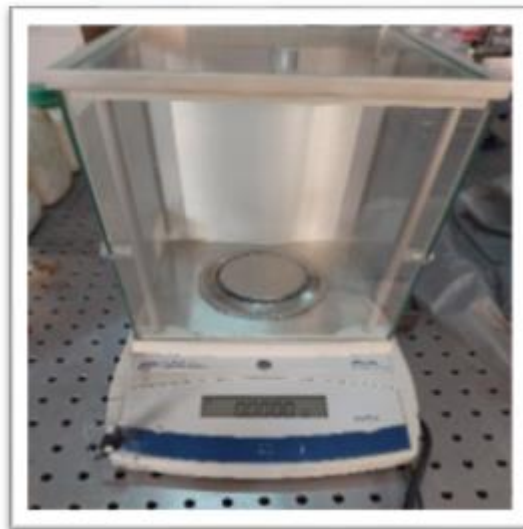


Figure (2.3) sensitive scale device

2-4 Optical Microscopes

These microscopes are used to examine the t surface topography and they are of two types, a transmitter and a reflector that uses ordinary white light as shown in figure (2.4).



Figure (2.4) optical microscope

2-5 FTIR Spectrometer

This were used for study the sample structure that, an IR source interacted with matter. Figure (2-5).



Figure (2-5) FTIR SPECTROMETER

2.6 Experimental set up

In this experimental set up , Various lasers, tripods, and magnetic bases were used, as well as an optical table and a single fiber for the visible area. The effect of the laser on different metals was done, and the reflected and dispersed laser spectrum was taken by ocean spectrum analyzer (190-1100) nm as shown in figure (2-6).

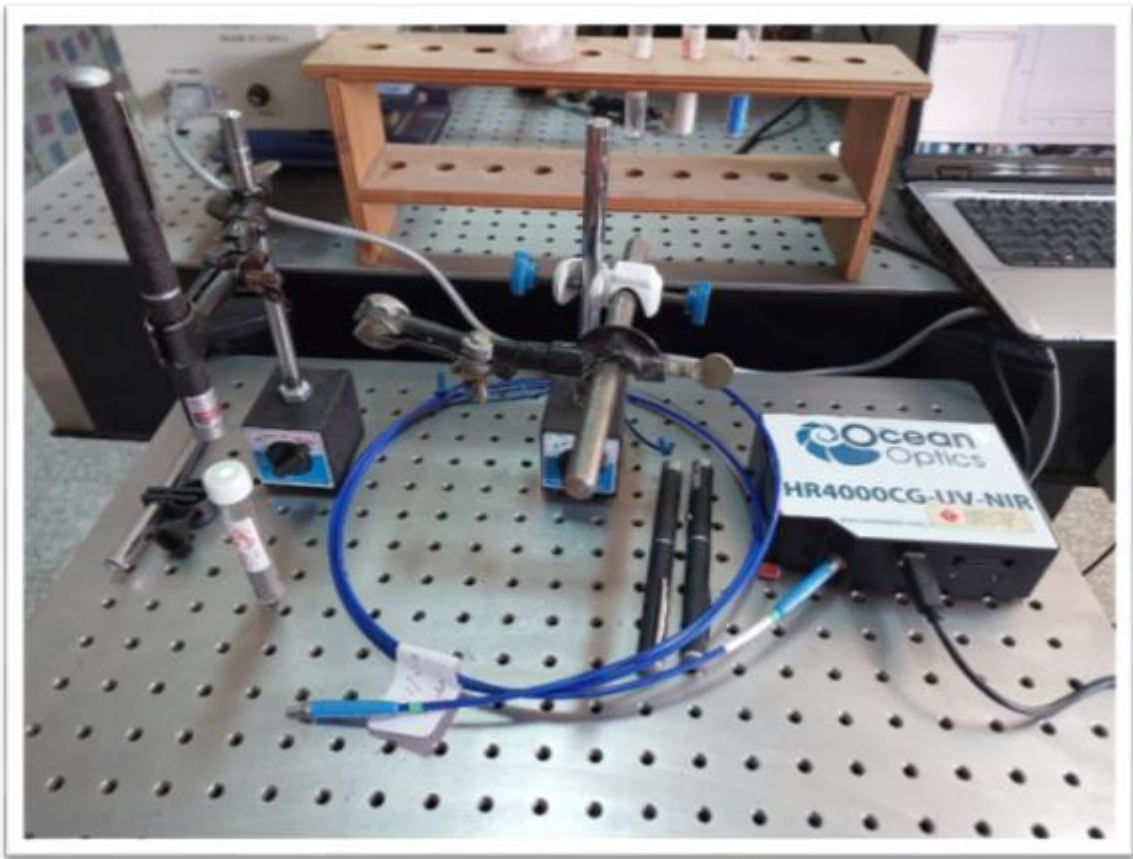


Figure (2-6) experimental set up

Results, discussion and Conclusions

In this paper, the interaction of the electromagnetic beam (laser) was studied. A three different minerals were taken in the solid state and in the form of powder, and 5 g of them were weighed in clean, transparent cans (copper sulfate, cobalt, aluminum welding powder), and 3 pure silver, copper, and gold were weighed in the solid state in the form of pieces, compressed discs, the weight of each Including (copper = 1 gm), (silver = 3 gm) gold (1 gm). Weighing was done using a sensitive scale with a sensitivity of (10^{-4}). Three types of visible laser diodes were used with lengths (405,532,630) nm and the spectrum of each of them was measured by a spectrum analyzer from **(Ocean Optics)** for the range from (190-1100) nm.

3-1 laser spectrum

In this experiment we study and examine laser wave length by using spectrum analyzer from **(Ocean Optics)** as shown in figures (3.1,3.2,3.3),green, blue, red diode lasers spectrum. Results shows intense peaks in (532,405,650)nm that corresponding to lasers wave length.

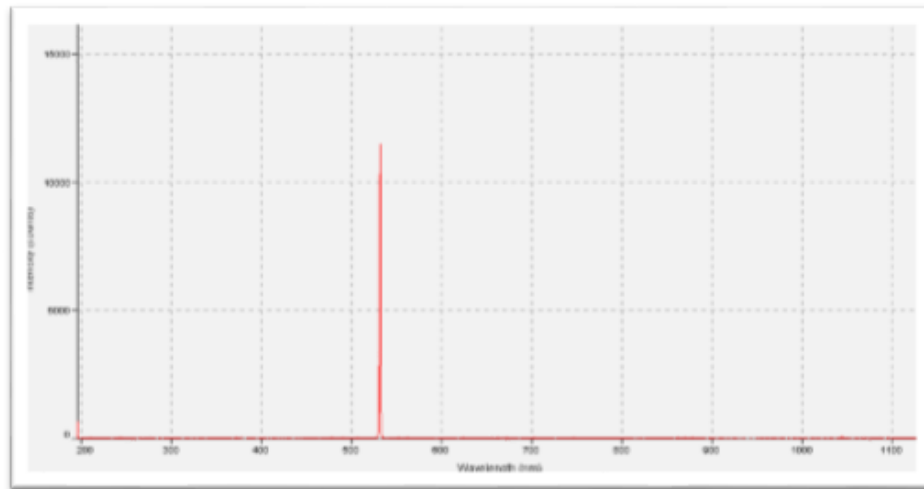


Figure (3.1) laser diode (532)nm spectrum

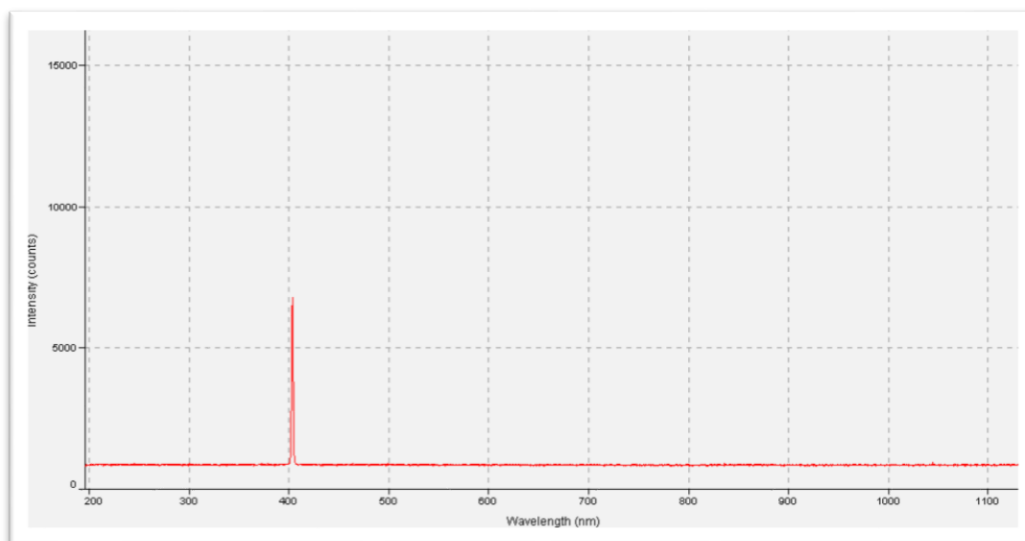


Figure (3.2) laser diode (405)nm spectrum

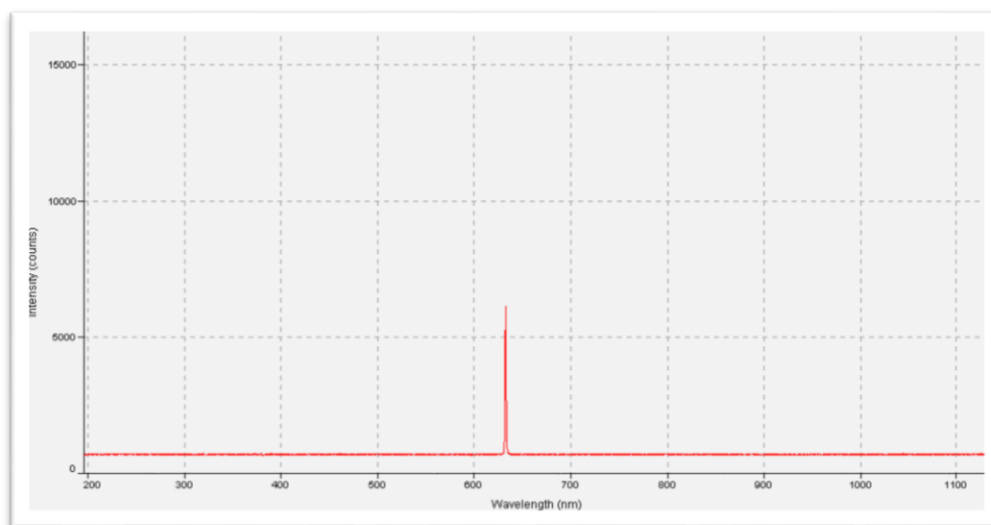


Figure (3.3) laser diode (650)nm spectrum

3-2 Microscopic examination using a reflecting and transmission microscope

In this experiment, pictures were taken by reflecting and transmission microscopes with different magnifications for the materials used, powder and minerals. The surface of the materials was studied before and after the effect of the laser for the reflecting microscope, and the models were gold, copper and silver. As for the transmission microscope, the surface composition of the samples in the form of powder was studied.

3-2-1 Reflecting Microscope

In this experiment, microscopic examinations were taken of the surface of metal samples (copper, silver, and gold) with different shapes and thicknesses of 2-3 mm, with a magnification capacity of 100 times. The microscopic images were as follows, shown in the figures(3.4,3.5,3.6) before and after the laser effect. Scratches and pits can be observed on the surface of the samples after the laser impact.

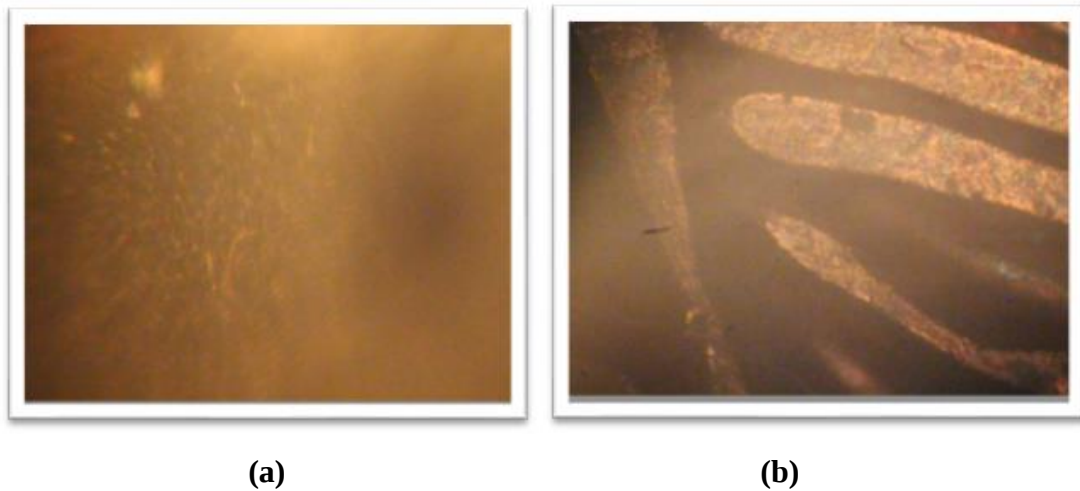
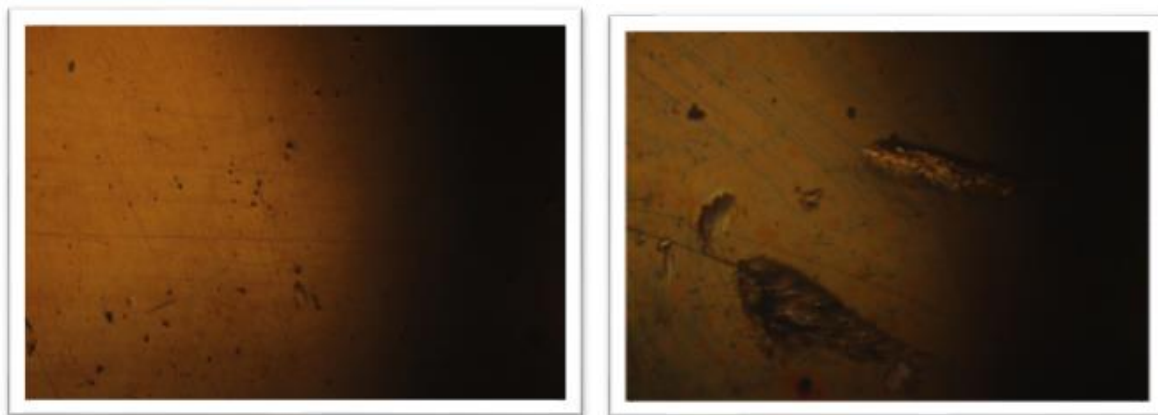


Figure (3.4) : microscope image for copper (a)before laser (b) after laser effect



Figure (3.5): microscope image for silver (a)before laser (b) after laser effect



(a)

(b)

Figure (3.6): microscope image for gold (a)before laser (b) after laser effect

3-2-2 Transmittances Microscope

In this experiment, a transmission microscope was used with a magnification of 50 times to study the composition of powdery samples (copper sulfate, aluminum welding powder, cobalt) through the interaction of the light beam with the material as shown in the figures(3.7,3.8,3.9). From observing the images of the transmitting wave, the structural shape of the powders can be measured using the electromagnetic beam (normal white), as it shows the shapes of the material and it was formed in the form of circles, cubes, or clusters.

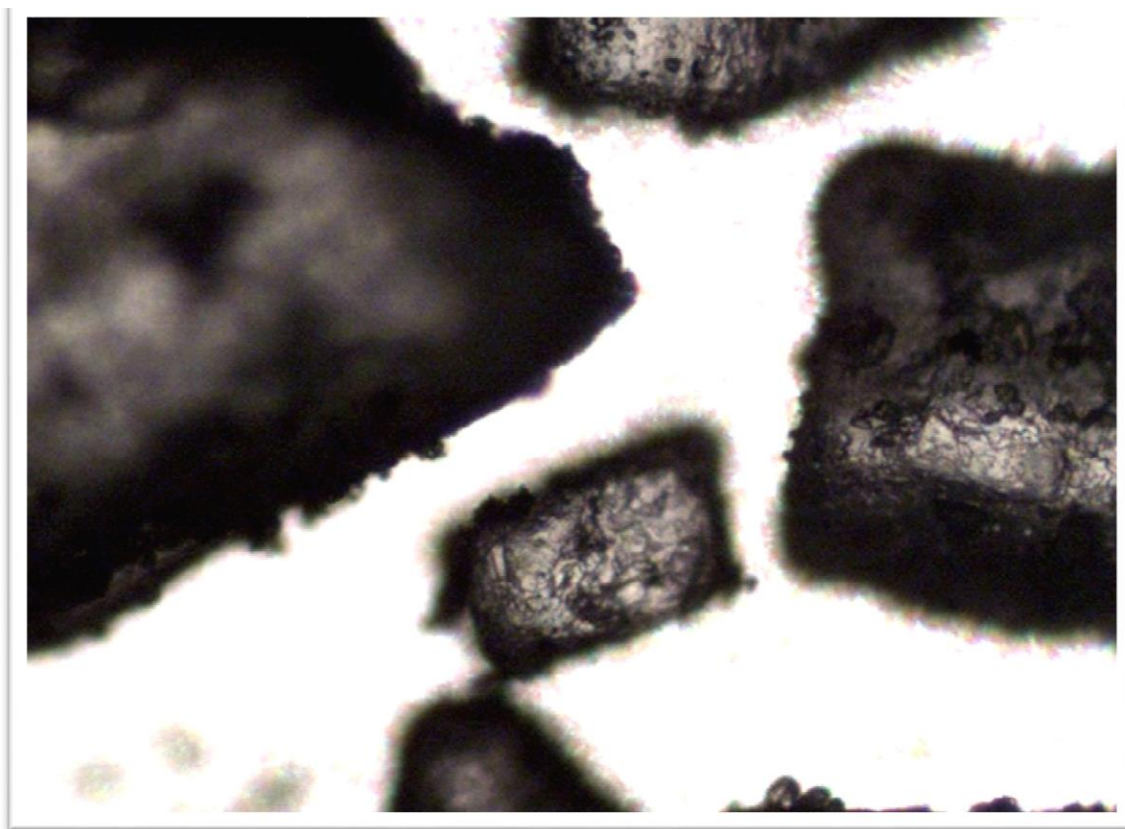


Figure (3.7): microscope image for aluminum welding powder



Figure (3.8): Microscope image for cobalt powder

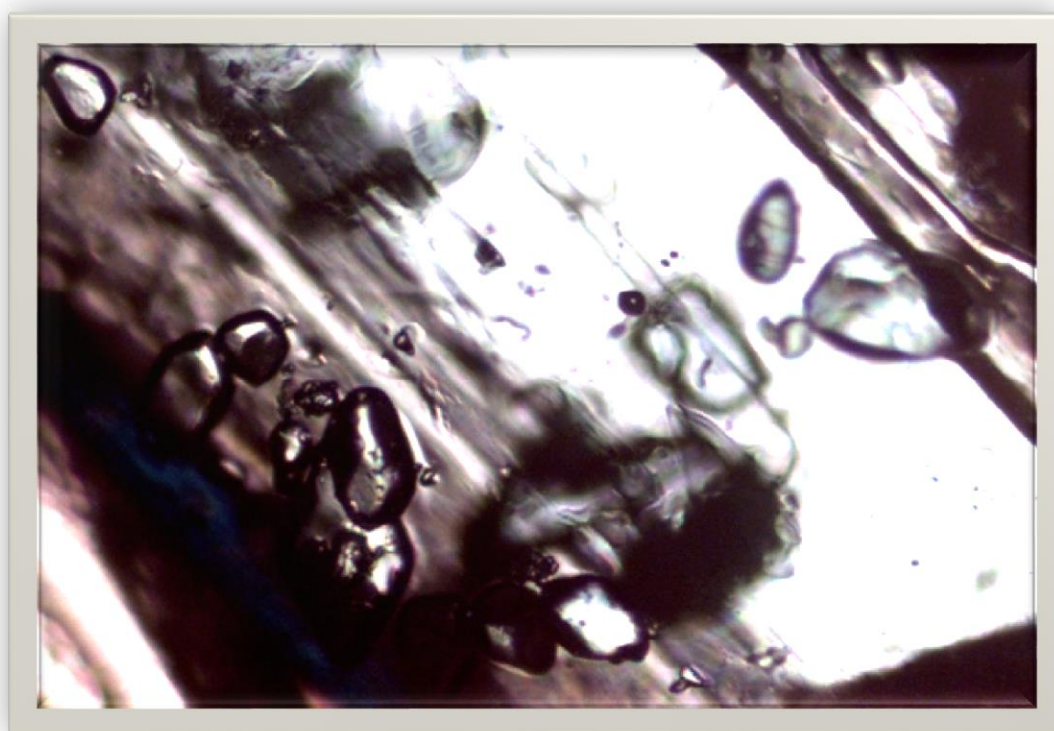


Figure (3.9): Microscope image for copper sulfate powder

3-3 FTIR spectrometer

In this examination, an infrared laser spectrum was used in the FTIR spectrometer (4000-400) cm^{-1} to analyze the structural components of the some mineral and powder samples, and they were as follows, as shown in the figures (3.10,3.11,3.12,3.13,3.14). From observing the visible and absorbed infrared spectra of the samples, the appearance of strong vibrational spectra was observed for almost all regions.

3-4 laser Induce Fluorescence (LIF)

In this experimental arrangement, the laser spectrum was used to generate the induced fluorescence, where three visible diode lasers were used, and the induced fluorescence spectrum was recorded by a spectrum analyzer using a single-mode fiber linked by the computer. In each examination, each type of laser is used on metals and powders, as shown in the figures (3.15-3.32). The laser-induced fluorescence spectrophotometer is a powerful tool that showed strong and effective spectra for all the sources used.

3-4-1 LIF with 532 nm

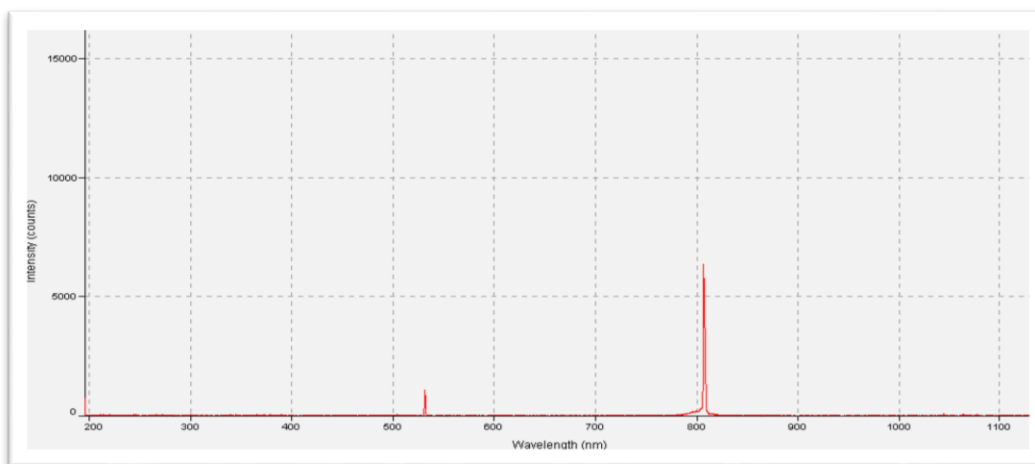


Figure (3.15) laser Induce Fluorescence with laser diode (532)nm spectrum for cobalt powder sample

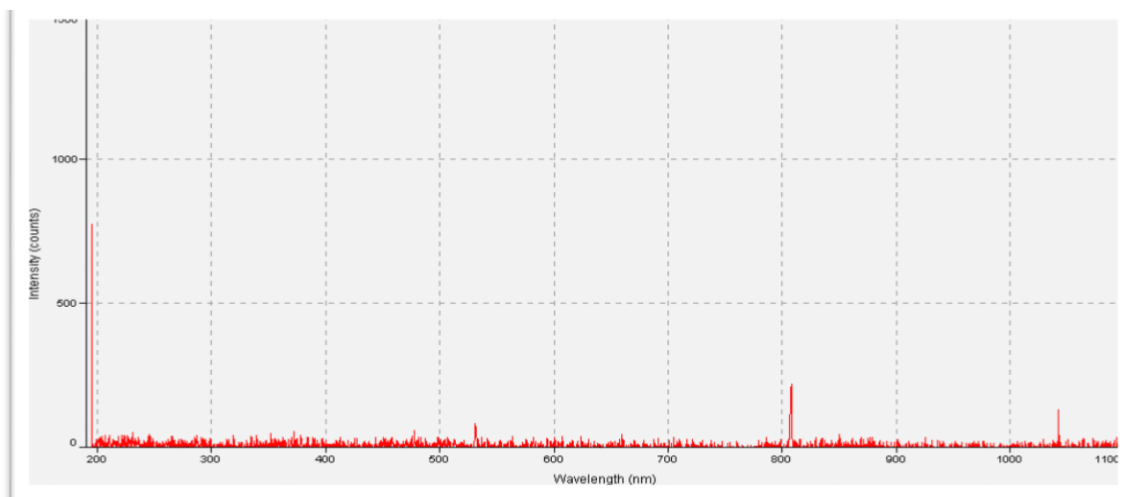


Figure (3.16)laser Induce Fluorescence with laser diode (532)nm spectrum for copper sulfate sample

Conclusions

1. Laser radiation is a powerful tool used in the study of matter

2. Microscopic examination of the materials reveals the topography of the surface as well as the structural shape of the materials, so it helps to understand them and how to use them in different applications.
3. The use of FTIR spectrometer helps to study the internal structure of materials through the interaction of infrared laser radiation with the material.
4. The use of laser-induced fluorescence technology is very successful in studying the properties of materials and thus its application in various fields.

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