Nd:YAG Laser Report

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Abstract

Neodymium Yttrium Aluminum Garnet lasers (Nd:YAG) have numerous applications in the world today. These include the medical and scientific fields for processes such as Lasik surgery and laser spectroscopy. A Nd:YAG laser can be operated in a continuous wave(CW) Q-switched or mode-locked regimes. A Q-switched laser produces repetitive pulses of tens of nanoseconds duration while a mode-locked laser produces pulses of tens of picoseconds duration each. A Nd:YAG laser can be optically pumped using lasers of several different wavelengths. This paper will discuss some of the basic characteristics of the Nd:YAG laser such as the efficiency, atomic levels, optical pump source and modes of operation.

Introduction

Neodymium doped Yttrium Aluminum Garnet (Nd:YAG) lasers were first invented by J. E. Geusic, H. M. Markos and L. G. Van Uiteit in 1964 at Bell Labs [1]. It was developed in the same technology as the Ruby Laser. The gain medium is the YAG crystal which is doped with around 1% neodymium by weight. When they were first invented, the lasing medium for YAG lasers were stimulated optically by flash lamps. In the world today, YAG lasers have numerous applications in the medical and scientific field for processes such as Lasik surgery and laser spectroscopy. This paper will discuss some of the general properties of a Nd:YAG laser system.

Laser Basics

Nd:YAG lasers are four level laser systems which means that there are four energy levels involved in laser action. The decay rates of these levels are around 230 ns. The advantage of a four level laser system as opposed to a three level laser system is a lower threshold pump power [2]. A Nd:YAG laser can be operated in a continuous wave(CW) Q-switched or mode-locked regimes [3]. A Q-switched laser produces pulses of tens of nanoseconds duration while a mode-locked laser produces repetitive pulses of tens of picoseconds duration. A Nd:YAG laser can be operated at several different wavelengths including 946 nm, 1064 nm, and 1322 nm depending on the cavity employed and the pump source [4]. Lower wavelengths of 473 nm, 532 nm, and 661 nm can be produced by frequency doubling or tripling of Nd:YAG radiation. At a wavelength of 946 nm, the laser is no longer a four level laser system but a quasi-three-level system [5]. The most common and efficient wavelength of a Nd:YAG laser is 1064 nm which has been shown to have a quantum efficiency up to 50% [6]. The optical pump source can either be a discharge flash lamp or a laser diode. Discharge lamps have been used the most in the past due to their lower prices but laser diodes are more efficient and their price has decreased so that they are increasingly being used as the pump. Flash lamp power is distributed over a wide wavelength range and is only available in short pulses and all wavelengths are absorbed by Nd:YAG crystal. The maximum output power of a Nd:YAG system using flash lamps as the optical pump source is 2000 watts. Using a laser diode, the output power can only reach about 10 watts but can be higher in pulsed laser form with an average power of about 50 watts. The typical divergence of a Nd:YAG laser is between 3-5 mr. This laser system can be formed using either a standing wave or ring cavity which can vary in length depending on your particular application needs.

Optical Pumping

The Nd:YAG laser uses an optical pump to excite atoms to provide the necessary gain for the laser. The optical pump source is either a discharge lamp or a semiconductor laser. The goal in deciding on an optical pump source is to choose a pump laser which produces an output spectrum that matches the laser pump bands (absorption band) of the YAG laser. No pump laser will be an exact match but one which encompasses the highest absorption region of the YAG laser would be best. For a discharge lamp such as krypton arc lamps, they are a continuum source of moderately poor overlap with the pump bands of solid-state lasers. However, these lamps can deliver up to 20,000 watts of pump power per lamp. In contrast, a semiconductor diode laser can be constructed so that the laser radiation almost precisely coincides with the pump bands of the laser. However, semiconductor lasers are difficult to construct with greater output power than a few hundred watts. Figure 1 shows the pump absorption bands of the YAG laser in the spectral range of 700 – 900 nm which could be used to determine the optical pump source.

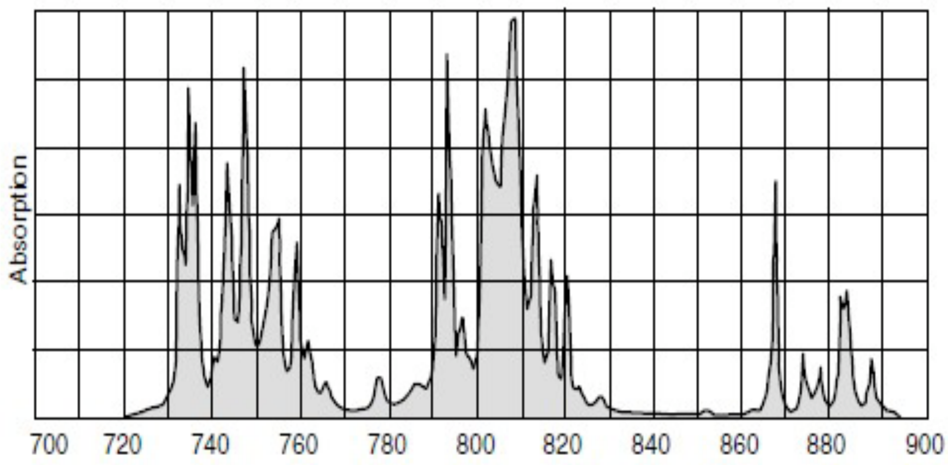

Figure 1: Diagram of the pump bands for Nd:YAG laser [7]

From the figure, we can see that the optimum pump bands are from 730-760 nm and 790-820 nm with the peak absorption wavelength at 808 nm. This signifies that most efficient pump source would be one with a wavelength around 808 nm. So one choice for a laser design would be to use a semiconductor diode laser which operates at 808 nm as the optical pump source. This laser matches the pump bands of the YAG laser. Due to the good match between the pump absorption bands and laser diode output emission, there is very little power that would be lost as heat within the YAG rod. This reduces the effects of heat induced birefringence in YAG rod. A discharge lamp produces high amounts of UV also which can cause damage to the materials that make up the YAG rod. This is not a problem with the semiconductor laser. As far as the lifetime of the pump source, a semiconductor laser can last two orders of magnitude longer in pulsed operation and around twenty times longer in CW operation. The output of a semiconductor laser is a narrow band of light which can provide high power. Since the semiconductor laser's emission is absorbed virtually completely by the YAG rod, efficiency rates of up to 50% can be achieved as compared to only 3% by discharge lamps due to the large spectral emission.

Absorption and Emission

For the laser system to work, there has to be an interaction between photons and the gain medium. This interaction involves absorption or emission of radiation. In the case of absorption, there is an upward transition from a level with energy E_1 to a level with energy E_2 when the energy of the incoming photon is $E_{ph} = E_2 - E_1$. Emission of a photon will take place if there is a transition from a state with energy E_2 to a state with energy E_1.

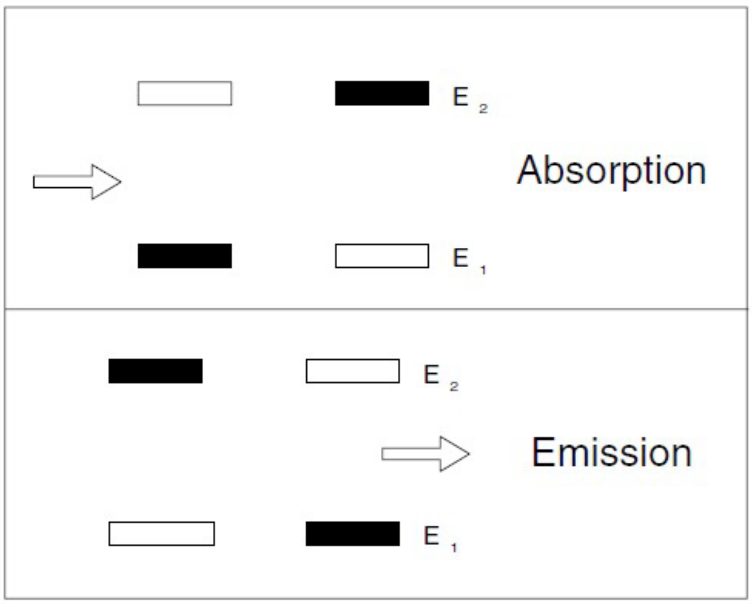

Figure 2: Absorption and Emission [7]

Figure 2 shows the processes of absorption and emission. An external field is necessary for absorption. Emission of a photon can be induced by an external field. This is referred to as induced emission. An excited atom can emit a photon even without an external field. This is known as spontaneous emission. Figure 3 shows a few of the energy levels involved in the Nd:YAG laser system. There are other levels as well but these are most relevant to the wavelength of our optical pump source which has a wavelength of 808 nm.

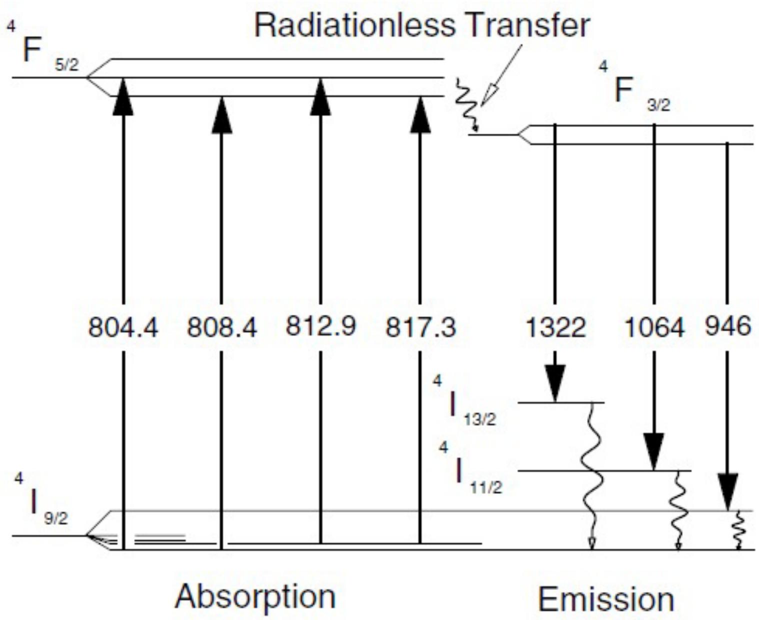

Figure 3: Energy Levels of Nd:YAG for optical pumping with semiconductor laser diode [7]

From Figure 3, we can see there are four transitions within the absorption region and three transitions within the emission region. The Nd atoms of the cavity lie within the YAG crystal which causes the energy levels to split up into a number of states. We can see from Figure 2.3 that the Nd:YAG crystal would be considered a four level system and each level is specified by its spectroscopic notation. In the absorption region, we have the ground state $I_{9/2}$ with five substates and the uper state $F_{5/2}$ which can be excited from five substates. The Nd atoms which are in the $F_{5/2}$ state will decay rapidly to the upper laser level $F_{3/2.}$ The most common transition for the ND:YAG laser is from the $F_{3/2}$ state to the $I_{11/2}$ state which emits a wavelength of 1064 nm. From this state, the Nd atoms decay back to the ground state and the pump process starts from the beginning. An example of this process in a more simplified form is shown in Figure 4.

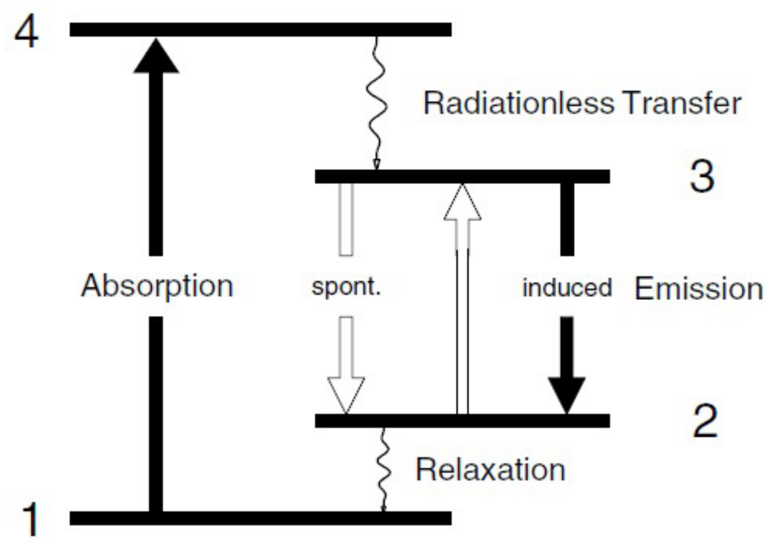

Figure 4: Four Level System [7]

Figure 4 gives the principle of operation of a four level laser system. When the optical pump is absorbed by Nd-ions in the YAG rod, they make a transition from the ground state 1 to the upper level 4. From here, a quick transition occurs to state 3. The laser transition from state 3 to state 2 occurs once the Nd-ions decay to level 2 and they quickly relax back to the ground state to begin the process again. Each transition can be defined as the emission or absorption of a photon of particular energy. For example, the transition from state 1 to upper level 4 absorption of a photon from the optical pump source. Similarly, in the $3 \rightarrow 2$ transition of Figure 4, a photon is emitted spontaneously or is induced by a field at $3 \rightarrow 2$ transition frequency. The transition from state 2 to state 1 is referred to as relaxation which is a transition which may be radiationless. Mechanical interactions such as collisions or vibrations can produce radiationless transitions. These transitions between states produce gain population inversion where there are more atoms in state 3 than in 2 within the laser resonator. The back and forth passage of photons between the mirrors stimulates the gain medium to emit additional photons which will all be in phase with photons already present in the laser cavity.

Conclusion

Nd:YAG lasers have proven to be very useful in the world today for many processes such as Lasik surgery. The gain medium which is the YAG crystal doped with Neodymium can be altered or changed and an entirely different type of material can be used as the gain medium to give slightly different operating characteristics. Nd:YAG lasers are four level laser systems which gives the advantage of a lower threshold pump power. Also Nd:YAG lasers are flexible since they can be operated in a continuous wave(CW) Q-switched or mode-locked regimes as well as operate at several different wavelengths. As time goes on, the efficiency of the Nd:YAG laser will increase which will make it an even better option for various applications.

References

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