DISCRETE OPERATING MODES OF ND:YAG LASER

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ABSTRACT

Lasers are devices that produce intense beams of light which are coherent,monochromatic and highly collimated. The wavelength of laser light is extremely pure when compared to other sources of light and all of the photons that make up the laser beam have a fixed phase relationship with respect to one another. Among all solid state lasers, Nd: YAG laser has an important role due to its high efficiency, possibility to tune it in different wavelengths from IR till UV and change pulse duration from milliseconds to picoseconds. Nd: YAG lasers can operate in either pulsed or continuous mode providing power outputs from 0.05W to 6000 W. Solid-state lasers operate at very low wavelengths and hence cannot be operated with the naked eye. One of the prime advantages of the Nd: YAG laser is the ability to operates in different modes like CW, pulsed, Q-switched, mode locked,harmoinic modes. This paper deals with the detailed properties of modes of operations of Nd: YAG lasers.

Keywords: *ND:YAG Laser, Characteristics of ND:YAG Laser ,Q-Switching, Mode Locking, Frequency Tuning*

INTRODUCTION

Laser is a device that emits EM radiation through a process of optical amplification based on the stimulated emission of photons. Lasers are devices that produce intense beams of light which are coherent,monochromatic and highly collimated. The wavelength of laser light is extremely pure when compared to other sources of light and all of the photons that make up the laser beam have a fixed phase relationship with respect to one another. There are different types of lasers available for research purpose, medical application, industrial and commercial uses. Lasers are often described by the form of lasing medium they use such as solid state, gas, excimer, dye and semiconductor lasers. Lasers have been used for more than 40 years in different fields of application starting from simple laser micromachining processes for micro-electro-mechanical systems (MEMS), such as cutting, drilling pulse laser deposition of coatings and films,medical diagnosis, treatment and therapy etc. Nd: YAG (neodymium-doped yttrium aluminum garnet) is a crystal that is used as a lasing medium for solid-state lasers. Among solid state lasers, Nd: YAG laser has an important role due to its high efficiency, tuning capability in different wavelengths from IR till ultraviolet and change pulse duration from milliseconds upto picoseconds. The dopant, triply ionized neodymium Nd(III), replaces a small amount (in proportion) of the yttrium ions in an event of crystal structure of the yttrium aluminium garnet(YAG), since the two ions are of similar size. It is the neodymium ion which evinces the lasing action in the crystal, Generally the crystalline YAG is doped with around one percent neodymium by atomic percent. Nd: YAG lasers can perform in pulsed as well as continuous mode providing power outputs between 0.05-6000 W. Solid-state lasers operate at very low wavelengths and hence cannot be operated with the naked eye. Operators must wear special eyeglasses or use special safeguards to prevent damage to the retina.

CHARACTERISTICS OF ND:YAG LASER

Nd: YAG is a four-level gain medium, offering substantial laser gain even for moderate excitation levels and pump intensities. The gain bandwidth is relatively small, but this allows for a high gain efficiency and thus has low threshold pump power. Nd:YAG lasers can be diode driven or lamp driven .Lamp pumping is feasible due to the broadband pump absorption mainly in the 800 nm region and the four-level features. The most common Nd:YAG emission wavelength is 1064 nm. Also different outputs such as 532, 355 and 266 nm can be generated by frequency doubling, frequency tripling and frequency quadrupling, respectively.Other emission lines are at 946, 1123, 1319, 1338,1415 and 1444 nm. When used at the 946 nm transition, Nd: YAG is a quasi-three-level gain medium, requiring significantly higher pump intensities. All other transitions are four-level transitions. Some of these, such as the one at1123 nm, are very weak transitions , so that efficient laser operation on these wavelengths is difficult to obtain: Even a moderate gain requires a high excitation density, which favors to quenching effects, in addition, lasing at 1064 nm, the wavelength with much higher gain, has to be suppressed, for example by using suitable dichroic mirrors for building the laser resonator.

Q-SWITCHING

This technique allows the production of light pulses with extremely high (in gigawatt) peak power.Q-switching is achieved by putting some type of variable attenuator inside the laser's optical_resonator.The attenuation inside the cavity corresponds to a decrease in the quality factor of the optical resonator.A high Q factor corresponds to low resonator losses per roundtrip, and contrariwise.The variable attenuator is commonly called a "Q-switch“.Initially the laser medium is pumped while the Q-switch is set to avert feedback of light into the gain medium. This produces a population inversion, but no laser operation yet occur since there is no feedback from the resonator. As the medium is pumped more the amount of energy stored in the gain medium increases.After a certain time the stored energy will reach some maximum level. the medium is said to be gain saturated. At this point, the Q-switch device is quickly swaped from low Q to high Q, allowing feedback and the process of optical amplification by stimulated emission to begin.Because of the large amount of energy already stored in the gain medium, the intensity of light in the laser resonator builds up rapidly; this causes the energy stored in the medium to be depleted almost as quickly. The net result is a short pulse of light output obtained by the laser, termed as a *gigantic pulse.*

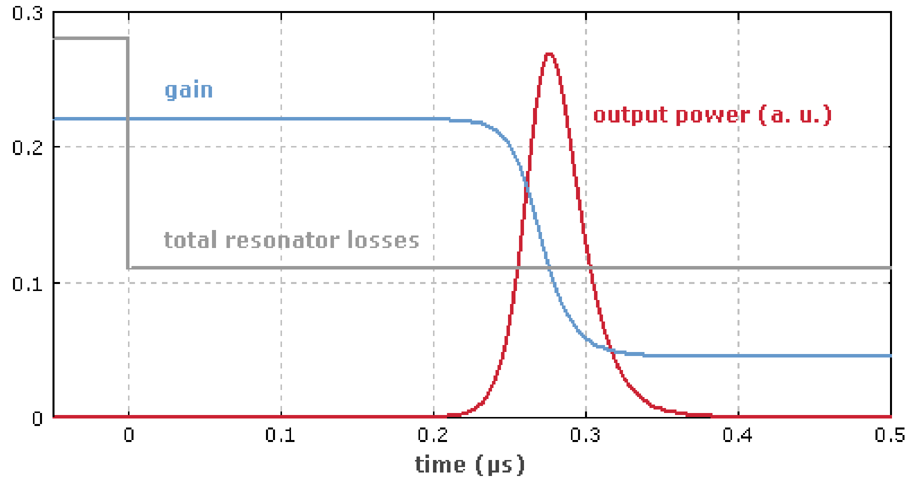

Fig 1: Evolution of gain and losses in an active Q-switched laser.

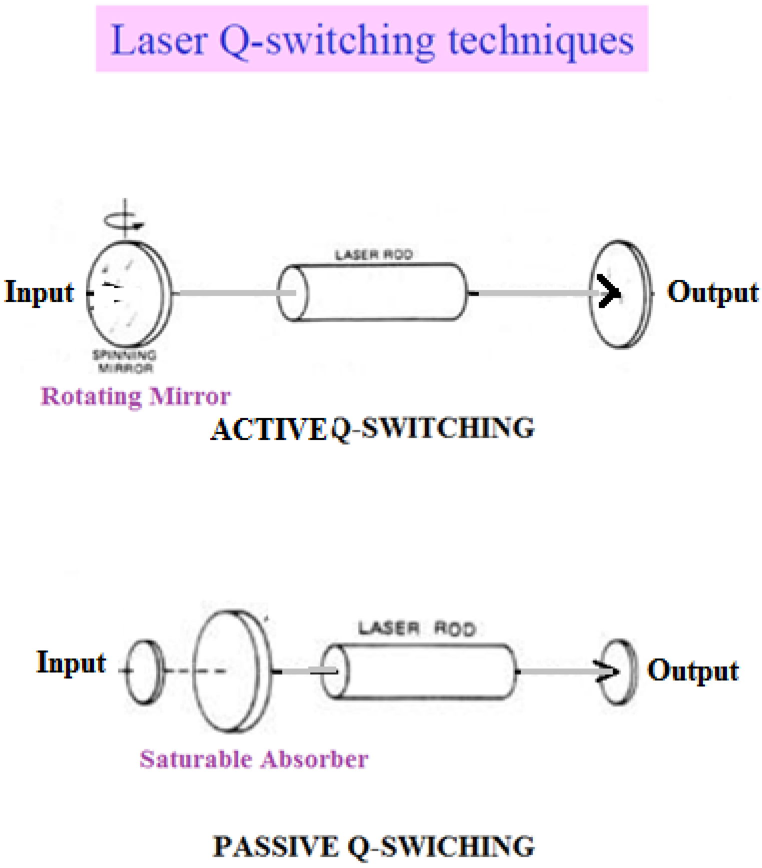

Fig2: Active and Passive Q-switching techiniques

In active Q-switch there is an externally controlled variable attenuator is being used whereas in passive Q-switch there is a saturable absorber.The saturable absorber consists of a material (such as a dye solution) whose transmission increases when the intensity of light exceeds some threshold.As the laser power increases, it saturates the absorber.A saturable absorber is also termed as an optical device that shows an intensity-dependent transmission.

MODE LOCKING

Mode-locking is a technique by which a laser can be made to produce pulses of light with extremely short duration, on the order of picoseconds or femtoseconds .The fundamental thing of this technique is to induce a fixed phase relationship between the longitudinal modes of the resonant cavity.Since light nothing but wave,bouncing between the two mirrors of the cavity, will constructively and destructively interfere with itself, leading towards the formation of modes between the two mirrors.These standing waves or modes form a discrete set of frequencies, called as the longitudinal modes of the cavity. These modes are the only frequencies of light that are self-regenerating and allowed to oscillate by the resonant cavity; whereas all other frequencies are suppressed by destructive interference.

Fig3: Mode locking

In active method an external signal is used to induce a modulation of the intra-cavity light whereas in passive method does not require such signal, but it relies on putting some element into the laser cavity which causes self-modulation of the light.

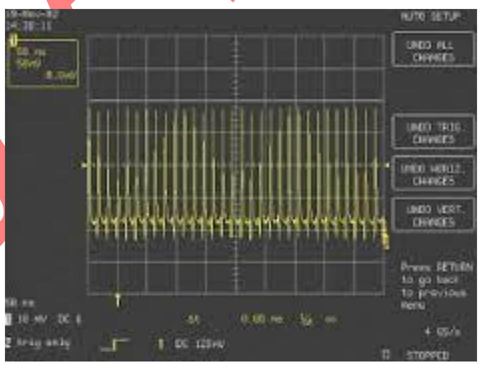

Fig4: Pattern of mode locking

FREQUENCY TUNING

Many lasers can operate at more than one wavelength To create a tunable laser, the cavity coatings must be sufficiently broadband to accommodate the entire tuning range, and a variable-wavelength tuning element must be introduced into the cavity, either between the

(IJAER) 2014, Vol. No. 8, Issue No. I, July **ISSN: 2231-5152**

cavity optics or replacing the high-reflecting optic, to introduce loss at undesired wavelengths. Three tuning mechanisms are in general use: Littrow prisms, diffraction gratings, and birefringent filters. Littrow prisms (see figure) and their close relative, the full-dispersing prism, are used extensively with gas lasers that operate at discrete wavelengths .In its simplest form, the Littrow prism is a 30-60-90-degree prism with the surface opposite the 60-degree angle coated with a broad-band high-reflecting coating. The prism is oriented so that the desired wavelength is reflected back along the optical axis, and the other wavelengths are dispersed off axis. By rotating the prism the retro reflected wavelength can be changed. In laser applications, the prism replaces the high-reflecting mirror, and the prism's angles are altered (typically to 34, 56, and 90 degrees) to minimize intracavity losses by having the beam enter the prism exactly at Brewster's angle. For higher-power lasers which require greater dispersion to separate closely spaced lines, the Littrow prism can be replaced by a full-dispersing prism coupled with a high reflecting mirror. Gratings are used for laser systems that require a higher degree of dispersion than that of a full-dispersing prism. Birefringent filters have come into general use for continuously tunable dye and ND:YAG lasers, since they introduce significantly lower loss than do gratings. The filter is made from a thin, crystalline-quartz plate with its fast axis oriented in the plane of the plate. The filter, placed at Brewster's angle in the laser beam, acts like a weak etalon with a free spectral range wider than the gain curve of the lasing medium. Rotating the filter around the normal to its face shifts the transmission bands, tuning the laser.Since there are no coatings and the filter is at Brewster's angle (thereby polarizing the laser), there are no inherent cavity reflection losses at the peak of the transmission band. A single filter does not have as significant a line-narrowing effect as does a grating, but this can be overcome by stacking multiple filter plates together, with each successive plate having a smaller free spectral range.

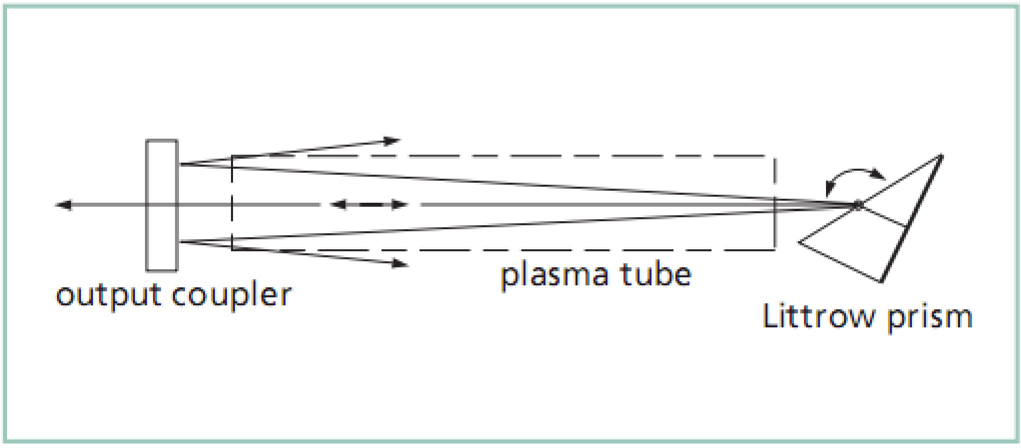

Fig5: Littrow prism used to select a single wavelength

Frequency doubling (or second harmonic generation) is a non-linear optical phenomenon. In the case of the Nd:YAG laser, frequency doubling will cause the conversion of 1064nm light (infrared and invisible to the human eye) to 532nm (visible green light). KDP is a tetragonal, negative uniaxial crystal. The crystallographic c-axis, which in the case of KDP is also the optical axis, points along the length of the crystal . For successful frequency doubling in a Nd:YAG laser, the optical axis of the crystal must be oriented at a ~45 degreee angle to the incident light. The laser should be polarized orthogonal to the optical axis.

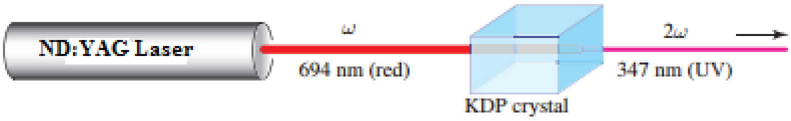

Fig6: Frequency doubling by KDP crystal

There are several crystals as listed below which can be used for frequency doubling

- For 800 nm wavelength : BBO
- For 806 nm wavelength: $LiIO_3$
- For 860 nm wavelength : $KNbO_3$
- For 980 nm wavelength : $KNbO_3$
- For 1064 nm wavelength : KH_2PO_4, KDP, LBO and BBO
- For 1300 nm wavelength : GaSe
- For 1319 nm wavelength : $KNbO_3$, BBO, KDP, KTP, $LiNbO_3$, $LiIO_3$, and ADP
- For 1550 nm wavelength : KTP, $LiNbO_3$

Stimulated Raman scattering in solid state crystals has been recently more widely employed for laser radiation frequency conversion.SRS converters is advantageous such as high conversion efficiency, no phase matching necessity, and easier handling compared to other cells.They can be used as frequency tuners in tunable lasers.The characteristics of SRS crystals at different wavelengths are as shown in following table

- Barium Nitrate $Ba(NO_3)_2$
- Potassium Gadolinium Tungstate $KGd(WO_4)_2$ or KGW

Stokes	KGW pumped @532 nm	KGW pumped @1064 nm	$Ba(NO_3)_2$ pumped @532 nm	$Ba(NO_3)_2$ pumped @1064 nm
1 Stoke	558	1177	563	1197
2 Stoke	588	1316	598	1369
3 Stoke	621	1494	638	1599
4 Stoke	658	1726	684	1924
1 Antistoke	507	970	503	957

Raman scattering termed as inelastic scattering of a photon.The material absorbs energy and the emitted photon has a lower energy than that of the absorbed photon energy is labeled as Anti-Stokes Raman scattering.The material loses energy and the emitted photon has a higher energy than that of the absorbed photon energy is labeled as Stokes Raman scattering.

There is also possibility to tune laser output at any intended wavelength .The scheme is as shown in figure below.

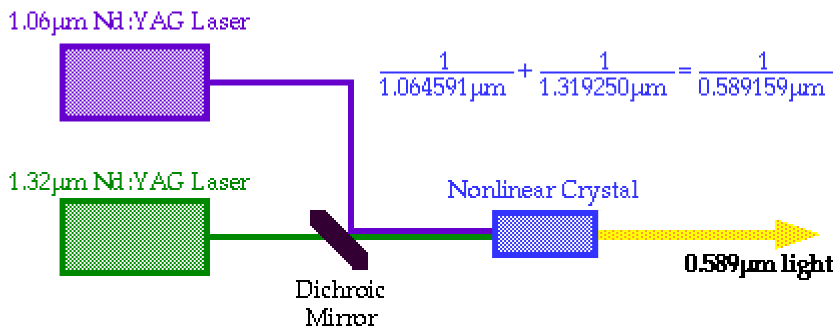

Fig7: Frequency Summing Laser

Here we are using two ND:YAG lasers with different wavelengths one is violet and other is green in colour.These wavelengths are passed through dichroic mirror which at one side of mirror is coated with anti-reflected material and another side is by fully reflected material which further passed through a non linear crystal (here any crystal can be used as per application) gives an output of yellow colour wavelength.

CONCLUSION

Nd: YAG laser has an important role due to its high efficiency, possibility to tune it in different wavelengths from infrared till ultraviolet and change pulse duration from milli to femtoseconds. Nd: YAG is a four-level gain medium, offering substantial laser gain even for moderate excitation levels and pump intensities. The gain bandwidth is small, but this allows for a high gain efficiency and thus low threshold pumping power. In development of modern medical lasers, Nd-YAG laser has gained an promising role in the large spectrum of treatment modalities. Laser techniques have become interesting alternatives in radical tumor resection and to palliative tumor treatment methods. Today, the most used solid state laser in dentistry field operates in the pulsed regime with pulse duration ranging from a milli to nanoseconds. Q-switched Nd: YAG normally operates in 300 ns, while Nd: YAG free-running presents operation in the 1-ms regime.

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