

Dye Lasers

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Introduction:

Dye lasers are perhaps the most versatile and one of the most successful laser source known today. Indeed, at the time of the discovery of this class of lasers by Sorokin and Lankard(1966), few could have anticipated their spectacular diversification and their significant contribution to basic physics, chemistry, biology and additional fields. Dye lasers offers to researcher both pulsed and continuous wave(cw) operations that is tunable from the near-UV to the near-IR.

Brief History:

Pulsed Dye laser:- The first dye laser was the ruby laser-pumped dye laser introduced by Sorokin and Lankard(1966). This report was quickly followed by the papers of Schafer et al(1966) and Spaeth and Bortfeld (1966).

The use of the Nitrogen laser as a direct UV excitation source for dye lasers was reported by several authors within a short period(Landrd and von Gutfeld, 1969; Lidholt, 1970; Capelle and Phillips, 1970; Myer et al., 1970; Broida and Haydon, 1970).

The first flashlamp-pumped dye laser was reported by Sorokin and Lankard(1967) and Schmidt and Schafer (1967). Flashlamp-pumped dye lasers were operated in an oscillator-amplifier configuration by Huth(1970) and flamant and Meyer(1971).

Dye lasers in solid state were introduced by Soffer and McFarland(1967) and Peterson and Snavely(1968).

Continuous-Wave Dye lasers:- The first cw dye laser was demonstrated by Peterson et al.(1970) These authors utilized rhodamine 6G dye excited by Ar ion laser. Important developments in cw dye-laser technology include he demonstration of a three-mirror folded cavity system by Kohn et al.(1971). The introduction of the dye jet by Runge and Rosenberg(1972). A further important landmark has been the demonstration of very stable single-longitudinal mode operation by Drever et al. (1983); Hough et al. (1984).

The wavelength range of cw dye lasers has been extended to UV spectral region using harmonic and sum frequency generation by Blit et al.(1978).

How Population inversion is achieved

All lasers depend in their operations upon the maintenance of a population inversion between air of energy levels in the lasing material. The organic dye laser is similar to the solid state laser in that the population inversion- the maintenance of greater population in the higher energy level of a pair of levels- is produced by “pumping” the material with light from the external source. The usual requirement on the pump light source is minimum intensity and a wavelength somewhat shorter than that of laser output.

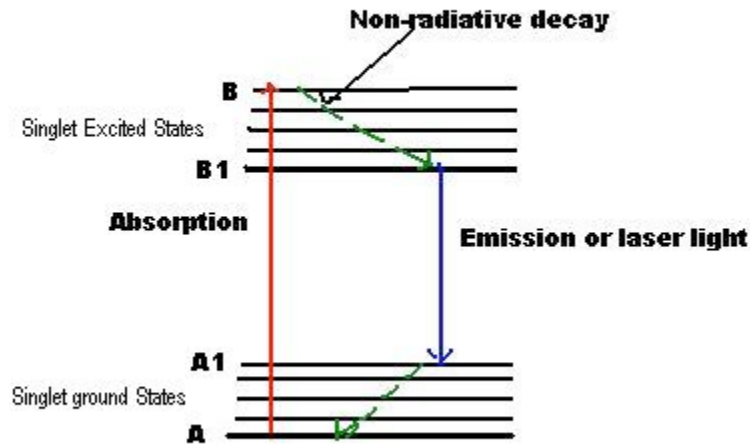


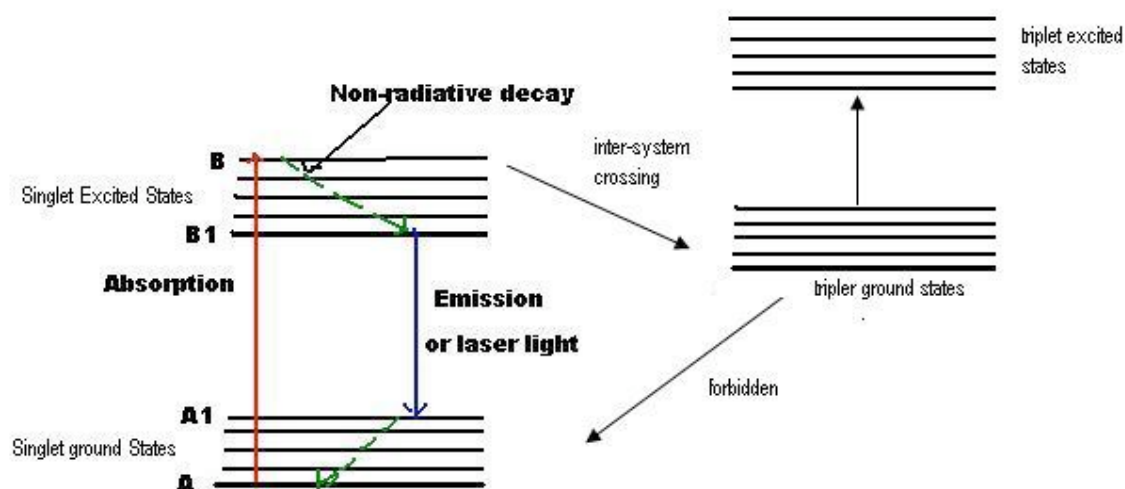
Figure 1 shows the energy level diagram of a simple solid state laser, and the diagram also applies to dye lasers in a very simplified way. Initially, the entire population of the medium concentrated at the bottom of the ground state level, with very little vibrational and rotational energy. This state is labeled A in the figure. When the medium is irradiated with light whose wavelength corresponds to the energy difference A-B, some of the ground state population is raised to the level B. This level, like level A, contains many vibrational and rotational sublevels, and pump wavelength is chosen so that the sublevel of B that are populated are the high-lying sublevels.

When a dye molecule is raised in energy to state B by the pumping light, it decays in a very short time to the lowest-lying sublevels of the state as indicated by B1. This decay occur with non-radiative transitions, that is, y transferring some

energy to the other molecules by collisions. Molecules in states B1 now radiate their energy and drop to one of the sublevels of the state A. It is most likely that they will drop to one of the upper levels of A, indicated as A1. If they do, the rerediated light will have a longer wavelength than pump light and this is well known phenomenon of fluorescence. Molecules in A1 will decay rapidly to the low-lying levels of A during collisions, just as they decayed non-radiatively from B to B1.

Since the sublevels B1 can be populated (in two steps) by the pumping light, and sublevel A1 are depopulated by collisions, it may be possible to generate a population inversion between B1 and A1, and thus set the stage for laser action. The requirement for obtaining inversion is that (a) B1 is pumped fast enough so that its population is greater than the population of A1, and (b) that A1 decays to A faster than the B decays by all processes. The first of these sets a power threshold for power radiation, below which laser action is not possible, the second is a function of the dye chemistry- the dynamics of the dye itself and of the solution it is in. If the requirements could be met, and if the energy levels structure of the dye were actually as simple as figure 1 suggests, then cw laser action in the dye would be a very easy experiment to perform.

Unfortunately, things are not so simple. A more realistic energy level diagram for an organic dye is shown below.



The states which correspond to the states shown in figure 1 are known as singlet states. In addition, a dye has triplet states, whose energy levels start at about the same energy as the first excited singlet state, and go on up from there. When dye molecules are

excited to the singlet states, some of them are diverted by collision to the triplet states. From here, radiation to the ground state proceeds very slowly, because transition is forbidden quantum-mechanically, and as a result lowest triplet state acquire a large population. Absorptive transition can take place from the lowest triplet state to other triplet states and it almost happen in organic dyes that such a transition can occur at a possible laser wavelength. The result is that, if a population inversion and laser action takes place between singlet levels, the medium becomes absorbing at the same wavelength as population accumulates in the triplet levels. When this absorption becomes greater than the gain, laser action ceases.

Triplet Quenching

Triplet absorption in flash lamp-excited dye systems is believed to be a major factor in the experimentally observed lack of synchronization between the pump pulse and the laser pulse. That is, the laser pulse terminates before the pump pulse ends. In fact, the laser pulse usually terminates before the intensity of the pump pulse has fallen below the threshold excitation value. This problem will be examined in more detail in a later section.

Attempts to construct a CW dye laser led to efforts aimed at controlling the triplet state population. One method often used is to add a second molecule to the dye solution to act as a so-called triplet *quenching agent*, which promotes triplet to singlet ground state transitions. Collisions between quencher and dye molecules are responsible for this de-excitation process. A number of substances have been discovered that have the correct energy-level structure to be effective as triplet quenchers. The one selected depends upon the specific organic dye to be used. For example, a chemical known as cyclooctatetraene (COT) is a good triplet quencher for rhodamine 6G.

In CW dye lasers rapid flow of the dye solution is also used to control triplet state population. The dye flows very rapidly through the active gain region where the argon beam is focused. In flowing through this region each dye molecule "sees" a pulse of pump light. If the dye is circulated fast enough, the individual dye molecule will be irradiated by a light pulse of duration *short* compared to the triplet decay ($T_2(p) S_0$) time but *long* with respect to the lifetime of the lasing transition ($B(p) A_1$). As an example, suppose the focused spot diameter of the pump beam is 10 microns. If the dye solution is circulated at a speed $v = 10$ m/sec, then each dye molecule "sees" a light pulse of duration t , where:

$$t = \frac{d \text{ focused beam}}{v \text{ (dye speed)}}$$

$$= \frac{10^{-5} \text{ m}}{10 \text{ m/sec}}$$

$$t = 1 \mu \text{ sec}$$

Tuning Mechanisms

CW dye lasers may be tuned to any wavelength over wide ranges for each dye used. Tuning may be accomplished by several methods. The most common methods will be described here.

Figure 3 is a diagram of a birefringent tuning element employed in many CW dye lasers. It consists of three birefringent elements mounted together at Brewster's angle. Light traveling through these elements is resolved into two components, one polarized along the fast axis and one polarized along the slow axis. These two components travel at different speeds and, thus, become more out-of-phase as they travel through the component. The first element of the birefringent filter is cut to a thickness that results in a retardation of one full wavelength in the visible region for the slow ray. This element is called a full-wave plate. When white light travels through it, one wavelength will actually be retarded by exactly one wavelength. Other wavelengths will be retarded slightly more or less. The wavelength that is retarded by exactly one full wavelength will emerge with its polarization unchanged. All other wavelengths will have an elliptical polarization with a horizontal component. These horizontal components will be reflected from Brewster's-angle surfaces in the system, producing losses for all wavelengths except the one passed unchanged by the filter.

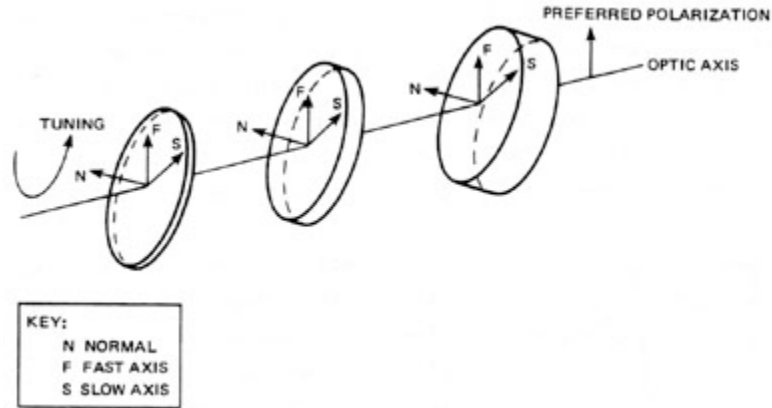


Fig-3 Three-element birefringent filter.

Additional filter elements are added for narrower bandwidths. The second element is twice the thickness of the first, and the third element is four times the thickness of the first. Each additional element further reduces the output linewidth. The three-element filter shown in Figure 3 has a typical output bandwidth of 0.025 nm.

The birefringent filter is tuned by rotation about an axis perpendicular to its optical surfaces. If the filter is positioned so that its "slow" axis is horizontal, the slow component of the light experiences the greatest retardation. As the filter is rotated, the angle between the slow axis and the direction of travel of the light changes, becoming a minimum when the slow axis lies in a vertical plane. Reduction of this angle also reduces the retardation effect. This allows the slow ray to travel faster as the slow axis becomes more vertical. The result is that different wavelengths experience exactly one full wave retardation at different angular orientations of the filter.

A second method of tuning CW dye lasers is the tuning wedge shown in Figure 6. This element is essentially a thin wedged etalon placed in the optical cavity of the dye laser. Tuning is accomplished by moving the tuning wedge back and forth in the cavity to allow the beam to pass through different thicknesses of the etalon.

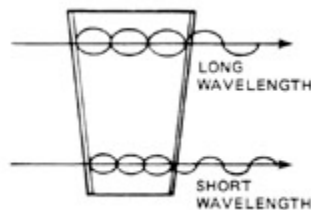


Fig.-4 Operation of a tuning wedge.

At any particular point on the etalon, light can pass through it with low loss only if the wavelength of light is correct for forming a standing wave inside the etalon cavity. All other wavelengths experience higher loss due to the etalon and will not lase. The etalon has only a slight wedge, and sliding it through the cavity will tune the laser over a range slightly greater than the visible spectrum.

The tuning wedge is composed of a fused quartz substrate. A reflective coating is deposited on this substrate to form the first partially-reflective surface of the etalon. The next coating element is a wedge-shaped coating of transparent material that forms the wedge-shaped spacer of the etalon. The final coating is another partially-reflective coating. The tuning wedge is mounted at Brewster's angle to minimize reflection losses.

A CW dye laser with either a birefringent filter or a tuning wedge will have several longitudinal cavity modes present in the laser output. For single-mode operation, a thicker etalon for mode selection must be added to the cavity. In some cases, two etalons are added for greater control of the exact laser frequency.

Rate Equations

To examine the relationship of the dye laser output to the pump power and beam geometry, it is necessary to solve the rate equations for population of the dye.

The rate equations based on the assumption that the collision decay times B-B1 and A1-A are fast compared to all other process. Thus rate equations contain only the total population in the states A and B, called $N(A)$ and $N(B)$ respectively and total population in the triplet state $N(T)$. The term that determine the time dependence are the pumping rate $P(t)$, itself a function of time, the decay time τ from B to A, the decay time from triplet to ground state, τ_T . In addition, there is a term, k , known as intersystem crossing rate, which is a rate at which molecules in excited singlet state B convert to the triplet state T. The rate equations are thus:

$$\frac{dN(B)}{dt} = [N(A) - N(B)]P(t) - \frac{N(B)}{\tau} - kN(B) \quad (1)$$

$$\frac{dN(T)}{dt} = kN(B) - \frac{N(T)}{\tau_T} \quad (2)$$

$$\frac{dN(A)}{dt} = [N(B) - N(A)]P(t) + \frac{N(B)}{\tau} + \frac{N(T)}{\tau_T} \quad (3)$$

The spontaneous emission time constant τ is so short compared to other processes in the cw dye laser that we can consider the states A and B in equilibrium at all times relative to this constant. Thus we can write

$$\frac{dN(B)}{dt} = [N(A) - N(B)]P(t) \quad (4)$$

$$\frac{dN(A)}{dt} = [N(B) - N(A)]P(t) + \frac{N(B)}{\tau} \quad (5)$$

$$N(A) + N(B) = \text{constant} = N(A + B) \quad (6)$$

The short time constant and equilibrium situation means that we can set the derivative equal to zero in equations 4 and 5 and the result is

$$N(B) = P(t)\tau N(A + B)/[1 + 2P(t)\tau] \quad (7)$$

$$N(A) = [1 + P(t)\tau]N(A + B)/[1 + 2P(t)\tau] \quad (8)$$

This pair of equations describe in a simple way the effect of the pumping radiation in generating a population in the upper laser state B. Note, however that it does not include the effect of the laser operation itself in changing population; the equations are used only to predict threshold.

The remaining set of equations describes the interaction of the triplet state with other states. This can be written as

$$\frac{dN(A + B)}{dt} = \frac{N(T)}{\tau_T} - kN(B) \quad (9)$$

$$\frac{dN(T)}{dt} = kN(B) - \frac{N(T)}{\tau_T} \quad (10)$$

$$N(A + B) + N(T) = \text{constant} \quad (11)$$

CW Pumped Dye Lasers

This section examines some design problems posed by a CW pumped dye laser and their solutions. The power density necessary to reach threshold for lasing in a typical organic dye laser is fairly large, $\sim 100 \text{ kW/cm}^2$. This value of irradiance generally precludes the use of CW arc lamps or other incoherent excitation sources. The focused beam from commercially available argon lasers, on the other hand, easily can exceed the required threshold power density. In addition, argon lasers have multiline outputs in a range of wavelengths from the near UV to the blue-green, which is convenient for exciting a reasonably large number of dyes. Thus, argon ion lasers are used almost universally for pumping CW dye lasers.

Basic Design Features

Figure 5 shows the basic design of an argon-pumped, CW dye laser. The optical cavity of the dye laser consists of three mirrors. The output coupler is a long-radius or flat mirror. Its transmission is typically between 10 and 20 percent. The two high-reflectance mirrors are curved and mounted at the proper separation and alignment to produce a focal point in the beam within the dye jet. Pump light in the form of the argon laser beam is focused into the dye jet at the same point as the dye laser beam.

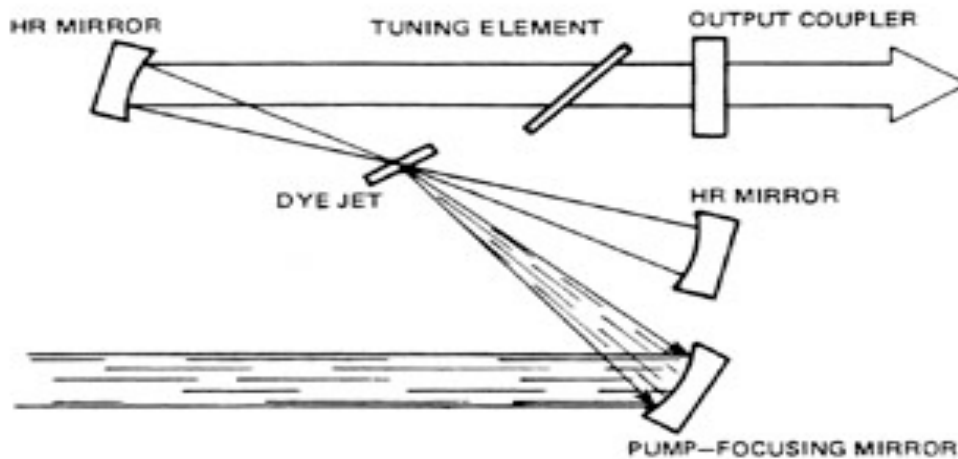


Fig.5 CW dye laser optically pumped with an argon laser.

Figure 6 shows the jet assembly of a CW dye laser. The dye is forced out of a small stainless steel nozzle in a broad, flat stream. The sides of this dye stream are relatively flat over the small area of the focused laser beams and serve as optical surfaces. The

jet is oriented at Brewster's angle to minimize surface reflections. To exceed the threshold power density by a factor of 5, say, the beam from a 1-watt argon laser must be focused down to a very small diameter, $\sim 10\text{-}20\ \mu\text{m}$. However, the focused beam can create a "hot spot" in the dye. Thermal gradients in the dye solution then result in optical inhomogeneities—that is, localized changes in the refractive index of the solution—and subsequent distortion of the output beam.

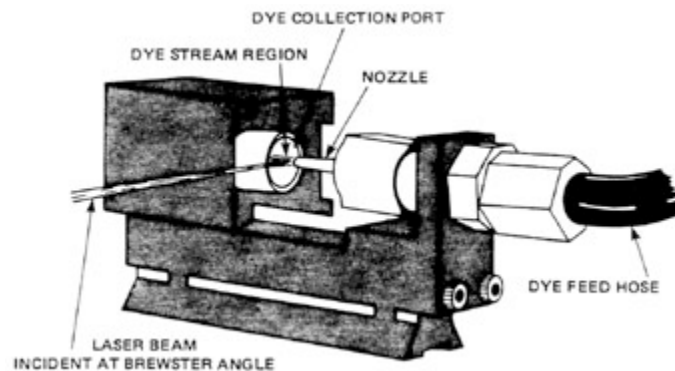


Fig.6 Nozzle assembly of a laminar-flow dye laser.

Inhomogeneities that arise from thermal distortion can be controlled by rapid flow of the dye solution ($\sim 10\text{-}20\ \text{m/sec}$) and by use of a dye solvent of which the refractive index is relatively independent of temperature, namely, water. This, in addition to convenience, is the reason that water often is used as the solvent for dyes in CW pumped dye lasers.

When water is used as a dye solvent, another problem arises, because most organic dyes do *not* dissolve readily in water. As a result, the original dye molecules tend to collect or aggregate, forming new molecules called *dimers* having the same chemical composition but of modified shape and structure. Therefore, these aggregates exhibit different energy levels, resulting in changes in absorption and emission characteristics. Unfortunately, dimers will not lase. This problem can be solved by the addition of a small quantity of de-aggregative or anti-dimerization agent (sometimes called a surface-active agent or surfactant) to the dye solution. A number of commercial detergents have been used as effective anti-dimerization agents, including liquid dishwashing preparations. In certain instances surfactants have the appropriate energy-level structure to act as triplet-quenching agents as well as to prevent the formation of dimers. Strictly speaking, dimers are aggregates of two molecules, while "*trimers*" are combinations of *three* molecules, and so on. The general term that describes a large number of molecules in an aggregate is *polymers*.

Ring Dye Laser

Figure 7 shows a ring dye laser designed for what is referred to as "single-frequency" operation. This laser produces an output with a spectral bandwidth of about 5 MHz.

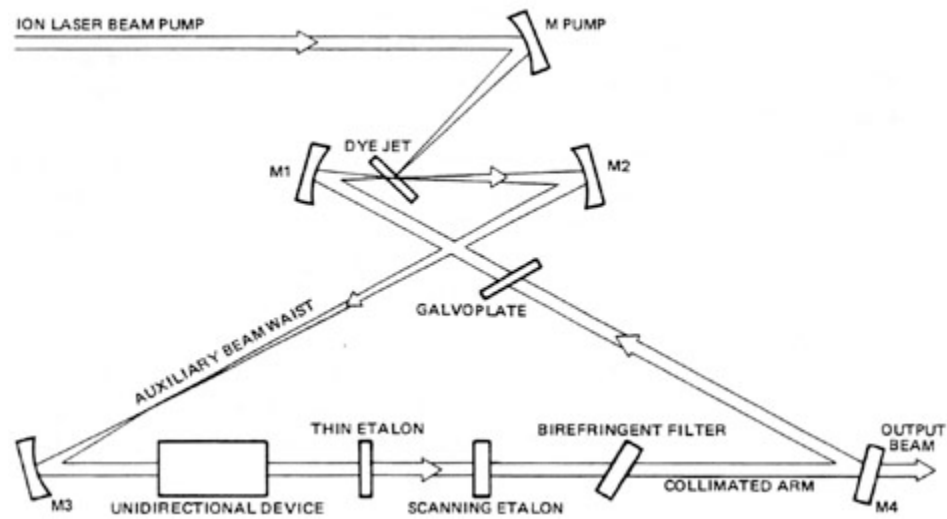


Fig.7 Single-frequency ring dye laser.

A ring laser has two advantages over one with a standing wave inside the optical cavity. First, the ring laser has no modes formed by the overall optical cavity and can, thus, lase at any frequency within the laser gain curve. Second, the ring laser makes greater use of the gain volume of the active medium. Standing waves in a typical laser cavity have nodes at which the intensity of the electromagnetic field of the laser light is always zero. No stimulated emission can occur at these points. This results in significant unused gain in the active medium. In a ring laser there is only a traveling wave moving in one direction. This produces a uniform stimulation inside the active medium resulting in the extraction of more of the stored energy.

In a typical laser cavity a standing wave is formed by two waves traveling in opposite directions in the cavity. In the ring laser one of these waves is eliminated by an unidirectional device composed of a Faraday rotator and polarizer. This device allows polarized light to pass through in one direction only. The other elements in the optical cavity of the laser in Figure 7 commonly are found in the cavities of both ring dye lasers and those with conventional cavities. The scanning etalon is added to produce a scan of the output laser wavelength over a specified spectral range. The galvoplate is used to change the laser wavelength very slightly by tilting to change the optical length of the cavity slightly.

Extremely short laser pulses may be produced with dye lasers by using a mode-locked argon laser as a pumping source and making the dye laser cavity the same length as the argon cavity. This results in synchronous pumping in which the active medium is pumped by a mode-locked argon laser pulse at precisely the right time to produce the maximum gain for a pulse in the dye laser cavity.

A variety of laser dyes are available for use throughout the visible spectrum and into the edges of the infrared and ultraviolet regions. Figure 8 shows the output powers and wavelengths of several of the most common dyes used in CW dye lasers.

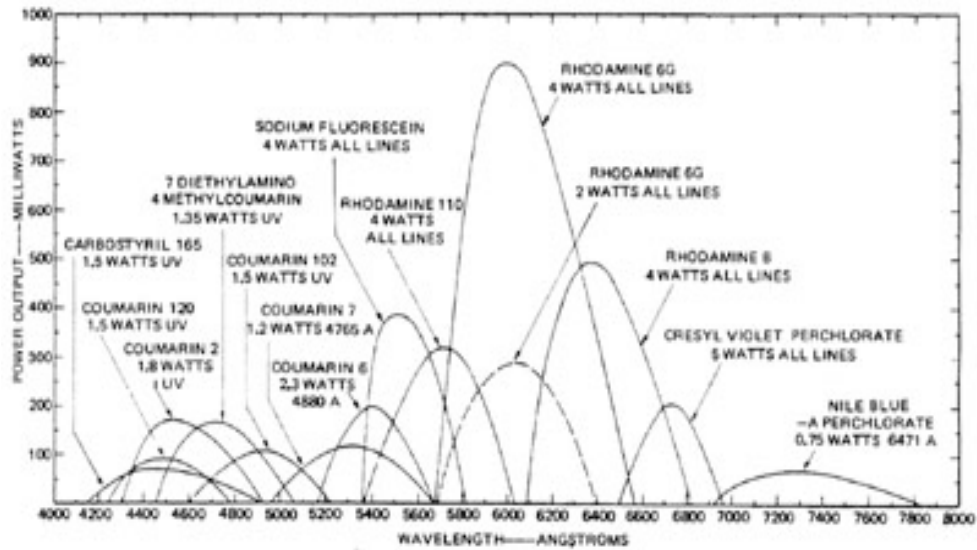


Fig.8 Dye laser output curves of some common laser dyes.

Wavelength and Output Power. The wavelength and output power of dye lasers depend on the choice of dye and pump source, as well as on the design of the laser. Fundamental-frequency outputs range from about 310 to about 1200 nm. Table lists a sampling of laser dyes and their outputs for various pump conditions.

The shortest wavelengths are possible only from pulsed lasers; the shortest wavelengths available continuous-wave (pumped by the ultraviolet lines of argon lasers) are about 370 nm. Considerably shorter tunable wavelengths, to about 200 nm, can be obtained by using dye laser pulses to drive second-harmonic generation or sum-frequency generation in nonlinear crystals. In sum-frequency generation, the dye laser frequency is added to that of a pump laser; in harmonic generation,

the dye laser pulses are combined with themselves to double the frequency. The second harmonic of continuous-wave dye output can be produced by placing a nonlinear crystal inside the dye cavity; the shortest wavelengths available are about 215 nm. β -Barium borate must be used to generate harmonic wavelengths shorter than about 250 nm.

The greatest variety of dyes, with the highest output powers, is available in the visible spectrum, but many dyes also are available for the near-infrared. The development of tunable titanium-sapphire lasers has diminished interest in infrared dye lasers, but the dyes continue to be used with existing dye lasers. Some manufacturers offer dye lasers which also can operate with a Ti-sapphire crystal substituted for the standard dye cell.

Each dye covers only a limited range of wavelengths, with peak output roughly in the middle of that range, where the dye can most efficiently convert pump light to laser output. As can be seen in Table, tuning range and peak wavelength for the same dye can differ considerably. A careful study of the literature would show considerably larger variations. In practice, dye tuning range, peak wavelength, and output power all depend on the pump source, solvent, dye concentration, and laser operating conditions. If the same dye is used with different pump sources, it may be dissolved in a different solvent and/or in a different concentration. The effects of differences in the optical configurations of different dye lasers can be difficult to identify because those data are difficult to summarize in tabular form. The lasing characteristics of dyes also can change if two dyes are mixed in the same solution, which is sometimes done to improve performance. Certain chemical additives also can improve dye performance, altering the tuning range while increasing output power.

Wavelength coverage of individual lasers can be limited by the cavity optics. Typically, cavity mirrors have low losses over a broader range of wavelengths than covered by any one dye, but not as broad as those covered by all available dyes. Extending tuning beyond that range requires additional sets of optics. The use of single-frequency optics, to limit linewidth to extremely small values, can restrict oscillation to only part of the wavelength range covered by a single dye.

TABLE 17.2 Characteristics of Selected Laser Dyes Plus Titanium-Sapphire for Different Pump Sources*

Dye name	Wavelength, nm		Pump source	Pump, W	Maximum dye output, W (at peak)
	Range	Peak			
Polyphenyl 2		383	Short-UV argon	3.4	0.25
Stilbene 1		415	UV argon	6.0	0.42
Stilbene 3	408-453	425	Nitrogen	—	—
(Stilbene 420)	410-454	424	XeCl	—	—
	412-444	424	Nd-YAG, 335 nm	—	—
	414-465	435	UV argon	7.0	1.0
Coumarin 102		477	Kr, 407-415 nm	4.8	0.58
(Coumarin 480)	454-510	470	Ar, ultraviolet	—	—
	457-520	478	Flashlamp	—	—
	457-517	478	XeCl	—	—
	459-508	475	Nd-YAG, 335 nm	—	—
	453-495	470	Nitrogen	—	—
Coumarin 30		518	Kr, 407-415 nm	4.6	0.38
Rhodamine 110	529-585	540	Ar, 455-514 nm	23	3.6
(Rhodamine 560)	529-570	541	Cu, 511 nm	—	—
	530-580	554	Flashlamp	—	—
	541-583	563	Nd-YAG, 532 nm	—	—
	542-578	555	XeCl	—	—
Rhodamine 6G	546-592	562	Nd-YAG, 532 nm	—	—
(Rhodamine 590)	563-625	586	Flashlamp	—	—
	563-607	585	Cu, 511 nm	—	—
	566-610	583	XeCl	—	—
	568-605	579	Nitrogen	—	—
	573-640	593	Ar, 455-514 nm	24	5.6
Dicyanomethylene	598-677	644	Cu, 511 nm	—	—
	600-677	635	Flashlamp	—	—
	600-695	637	Nitrogen	—	—
	607-676	635	Nd-YAG, 532 nm	—	—
	610-709	661	Ar, 455-514 nm	20	2.9
Ti-sapphire		790	Ar, 455-514 nm	20	3.6
Styryl 9	775-865	818	Nd-YAG, 532 nm	—	—
	784-900	822	Argon	—	—
	810-860	841	Flashlamp	—	—
Infrared dye 140	866-882	875	Nd-YAG, 532 nm	—	—
	875-1015	960	Kr, 753-799 nm	3.0	0.2
	876-912	884	XeCl	—	—
	900-995	936	XeCl	—	—
	906-1018	964	Nitrogen	—	—

*Pumping conditions and solvents differ, and experimental tuning ranges and power levels may differ dramatically. Note that some dyes are sold under different names.

SOURCES: Coherent Inc., Exciton Chemical Corp.

Output power depends on the choice of pump laser and the design of the dye laser as well as the choice of dye. Typically, manufacturers specify maximum output of Rhodamine 6G, a particularly efficient dye which can be used in all types of dye lasers and has a peak wavelength near 600 nm. Other dyes generally give lower power levels, as does Rhodamine 6G when operated away from its peak wavelength.

Dye laser power is proportional to pumping power above laser threshold. Output power depends on how well the excitation wavelength matches the absorption bands of the dye, and can be

influenced by pulse duration. This makes it important to understand the pump-light source when studying reports of dye laser performance. Table summarizes the advantages and disadvantages of various sources and lists important wavelengths.

Applications

1. Laser isotope separation

Isotope separation is the process of concentrating specific isotopes of a chemical element by removing other isotopes, for example separating natural uranium into enriched uranium and depleted uranium. This is a crucial process in the manufacture of uranium fuel for nuclear power stations, and is also required for the creation of a uranium based nuclear weapon. Plutonium based weapons use plutonium produced in a nuclear reactor, which must be operated in such a way as to produce plutonium already of suitable isotopic mix or grade.

In this method a laser is tuned to a wavelength which excites only one isotope of the material and ionizes those atoms preferentially. The resonant absorption of light for an isotope is dependent upon its mass and certain hyperfine interactions between electrons and the nucleus, allowing finely tuned lasers to only interact with one isotope. After the atom is ionized it can be removed from the sample by applying an electric field. This method is often abbreviated as AVLIS (atomic vapor laser isotope separation). This method has only recently been developed as laser technology has improved, and is currently not used extensively. However, it is a major concern to those in the field of nuclear proliferation because it may be cheaper and more easily hidden than other methods of isotope separation. Tunable lasers used in AVLIS include the dye laser and more recently diode lasers

2. Laser guide star

In 1982 a yellow dye laser was used in a laser guide-star demonstration, where the laser photons were tuned into the absorption band of sodium ions in the upper atmosphere. Relaxation of this excitation provided a distant light source (sodium D-lines) to give a measure of the distortion of a wavelength as it travel through the atmosphere. An adaptive optical system can then provide the conjugate to this distortion to optimize the delivery of laser light to a distant target.

3. Submarine tactical communication

It is well known that blue light propagates well in the ocean and this has been exploited for tactical communication between submerged submarines. Dye laser technology was used to demonstrate an efficient and compact blue-light emission at 455 nm for this application.

4. Medical uses

A dye laser was used for removal of “port wine” stains from skin. The output is tuned to the color of the pigment in the skin to destroy it through resonance; this technique has been developed to remove tattoos using the same principles. A further development has been the use of a dye laser for removing blood clots in the coronary artery (laser thrombolysis in cardiology); in this case the technique relied on the tuning the laser photons into the natural resonance of the blood in the clot. The products of the destructive interaction are removed using a catheter. In photo-dynamic therapy, a therapy technique which is used in cancer curing, we also use laser to destroy cancer cells.

Conclusion

Dye laser technology has advanced over last decades since the first demonstration of laser action in a dye based system. The simplicity and versatility makes the liquid-phase dye laser technology attractive for many applications, other attributes are its very broad spectral emission capability, including simultaneous multi-color emission. A big advantage of this technology, compared with any solid state device is the ease of removal of heat from the gain medium. This feature leads directly to the ability to operate these lasers at a high repetition rate with high-energy pulses, which permits a high average power output to be generated.

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