

Gas lasers

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Abstract. The important gas lasers which find wide applications in material processing are the CO₂ laser, the argon-ion laser and the excimer lasers. This paper briefly describes the basic concepts and the technology of these lasers.

Keywords. Laser; gas laser; ion laser; excimer laser.

1. Introduction

Lasers based on gaseous gain or active media constitute the largest number of lasers developed to date and are undoubtedly the most important ones on account of their wide spectral range, output power capability, spectral purity and versatility.

Though the first laser operated by Theodore Maiman in 1960 (Maiman 1960) was a solid state laser using a ruby crystal, efforts had been initiated to operate optical masers using gaseous media since the discovery of the maser by Gordon *et al* (1955). The operation of the first gas laser, which was a He–Ne laser, by Javan *et al* (1961) followed soon. Since then, research on gas lasers has attracted world-wide attention and initiated an avalanche of work involving ionized systems, neutral atoms and molecules. Three years later, one of the most important gas lasers, the CO₂ laser, was discovered by Patel *et al* (1964). In the same year Bridges (1964), Convert *et al* (1964) and Bennett *et al* (1964) obtained laser action in ionized argon. Till then gas lasers were operated in low-pressure electric discharges. Then followed the developments of electron beam pumping, chemical excitation, optical pumping, etc. which rapidly increased the number and scope of these gas lasers. These technological developments brought within their bounds the excimer lasers, hydrogen halide (HF, HBr, etc.), chemical lasers and a host of other infrared molecular gas lasers.

The use of gaseous material in laser has certain advantages compared to other media like solid state and semiconductor. The volume of gaseous medium can be large, which makes it suitable for high-power lasers. There is no possibility of damage to the medium, which occurs in high-power ruby and glass lasers. The medium is homogeneous, which allows a good quality laser beam. Heat can be removed easily in gas lasers by transporting the heated gas out of the lasing region. There is a wide variety of gaseous media which are capable of giving out laser radiation of different wavelengths in a wide range of the spectrum.

To date, laser action has been obtained on more than 7000 transitions in about 50 elements, 39 elements in ionic states and in more than 100 molecules, all in gaseous state. These cover, discretely, a wavelength range from 0.1 micron in ultraviolet to the millimetre (2.6 mm) region. Starting from output power of a few milliwatts and efficiency of less than one per cent, available power has reached terawatts of pulse peak power and has exceeded 100 kW continuous output power in CO₂ lasers with efficiency of over 10%.

There are some drawbacks also associated with gaseous media, e.g. the inability

to have large number densities comparable to those of solids and insufficient broadening of absorption lines to be efficiently pumped by broad-band sources or of emission lines to afford wide tunability in the output. The latter disadvantage is more than compensated by the fact that most of the gas lasers can be excited efficiently in an electric discharge and there exist many efficient gas lasers which can be deployed as optical pumps for the narrow absorption lines associated with gaseous media.

Today gas lasers are playing an important role in a wide range of industrial, medical, R and D, commercial and defence applications. We have listed, in table 1, those gas lasers which have been fully developed and have achieved a significant degree of commercial acceptance. The table also indicates some of their characteristics and areas of application.

The major gas lasers that are being used for various material processing applications are the CO₂ laser for applications such as welding, cutting, and heat treatment of metals and non metals, and the Ar-ion laser and the excimer lasers for micro-machining and several semiconductor processing applications in the electronics industry. In this paper I shall discuss these lasers in some detail.

2. Laser operation.

The basic design concept of most of the gas lasers is the same. It has been schematically depicted in figure 1. The gaseous medium is put into a laser tube usually made of glass or some ceramic (figure 1a) or in a chamber (figure 1b) at a pressure in the range of a few millitorrs to several atmospheres depending on the type of laser. The gas may be flowing or be sealed in the tube. The mirrors of the optical resonators are mounted either directly at the ends of the laser tube or external to the tube. The gaseous medium is usually excited by passing an electrical discharge current through it. Some lasers are operated in a continuous wave (CW) mode, some in a pulsed mode. Continuous operation is achieved by passing either direct current or r.f. current. For pulsed operation usually a storage capacitor is charged at a high voltage and then is discharged through the gas with a fast switch normally a spark gap for single-shot operation or a thyatron for high repetition rate operation (100 Hz to 100 kHz).

The electric field which produces the discharge is usually applied along the axis of the laser tube and this configuration is called longitudinal excitation (figure 1a). In some cases, particularly in high-pressure gas lasers, the electric field is applied perpendicular to the laser axis, and this is known as transverse excitation (figure 1b). In this configuration the voltage required for maintaining the discharge is less than that which would be required in longitudinal excitation and a larger gas volume can be uniformly excited. In order to couple the electric power in the gaseous medium suitable discharge electrodes are incorporated in the laser tube. In the electrical discharge the electrons which maintain the discharge current collide with gas atoms or molecules and either directly excite the lasing species to upper laser level or excite other gases which are mixed with the lasing species and they, in turn, transfer their energy to the lasing species through collisions. Thus population inversion is created and laser action follows.

In gas lasers the efficiency, which is defined as optical power output divided by input electrical power, ranges from less than 1% to as high as 30%. Thus only a

Table 1. Gas lasers and their areas of applications.

Type of laser	Principal wave-length (10 ⁻⁶ m)	Date of discovery and commercialization	Laser power	Area of application	Price of typical lasers**
1	2	3	4	5	6
Helium-neon	0.6328	1962/63	0.5-50 mW	AMC, GA, IP, ED, MD, R	1-2 mW, Rs. 8000
Ion					
Argon (Ar ⁺)	0.488, 0.514	1964/66	5 mW-15 W	MP, AMC, GA, IP, ED, MT, MD	4 W, \$ 12,000
Krypton (Kr ⁺)	0.647, 0.530		0.5-6 W	-do-	0.8 W, \$ 14,000
Xenon (Xe ⁺)	0.351		0.6 J/L, 30 Hz		\$ 65,000
Metal vapour					
Helium-cadmium	0.442, 0.325	1968/70	1-100 mW	AMC, GA, IP, MD, R	50 mW, \$ 13,000
Copper vapour	0.510, 0.578	1966/81	Ave. 1-100 W 200-20000 Hz	MP, R	10 W, \$ 35,000
Gold vapour	0.628	1978/82	Ave. 0.5-10 W 200-20000 Hz	MT	4 W, \$ 30,000
Excimer					
ArF	0.193	1975/76	0.1-0.5 J		
KrF	0.248		0.1-1 J	MP, MT, R	0.4 J, 100 Hz, \$ 50,000
XeCl	0.308		0.1-1 J		
XeF	0.350		0.1-0.5 J		
Carbon dioxide	10.6	1964/66			
CW					
Low power			1-100 W	MP, IP, MT, R, D	5 W, \$ 5,000 50 W, \$ 20,000 100 W, \$ 40,000 1 kW, \$ 100,000
Medium power			0.1-1 kW	MP, R	
High power			1-15 kW	MP, D	
Pulsed			600 J, 0.1 Hz, 1 microsec	MP, R, D	

Table 1 (Contd.)

1	2	3	4	5	6
Nitrogen	0-337	1966/69	5-30 nJ, 0-100 Hz, 8-10 nanosec	R	10 mJ, 20 Hz, \$ 3,000
Chemical					
HF	2-6	1967/77	1-200 W	MP, R	100 W, \$ 140,000
DF	3-7		1-150 W		
Iodine photo-dissociation	1-315	1964/83	3 J, 1 Hz, 2.5 microsec	MP, R	\$ 40,000
Far infrared	20-1000 (discrete wavelength)	1963/69			
Methanol			10-200 mW		100 mW, CW, \$ 46,000

*0-100 Hz, 0.01-0.35 microsec pulse duration.

**Laser Focus Buyer's Guide, 1986.

Abbreviations: MP, Material processing; AMC, alignment measurement, control; GA, graphic arts, including plate-making, colour separation, image setting and engraving; IP, information processing, including bar-code scanning, optical disc, information storage and laser printing; ED, entertainment, display; MT, medical treatment; MD, medical diagnosis; R, research; D, defence.

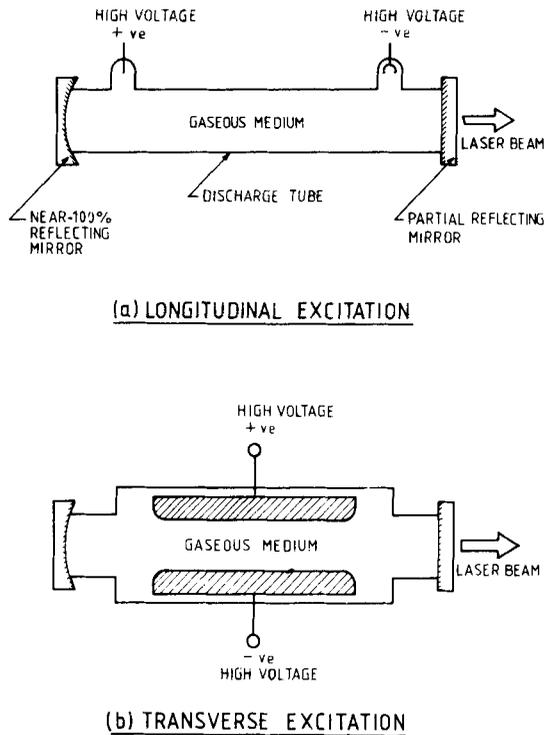


Figure 1. Essential elements of a gas laser.

part of the electrical power is coupled out as useful optical radiation and the rest is dissipated in the medium as heat. This raises the temperature of the medium. For each type of laser there is a certain range of gas temperature beyond which the laser output starts falling. This problem is particularly severe in high-power CW lasers. In low-power, sealed-off lasers heat is removed through the wall of the laser tube by either natural or forced air-cooling, or with water made to flow through a jacket around the tube. In medium- and high-power lasers the gaseous media themselves are continuously made to flow out of the lasing zone and replaced with fresh cooled gas, or are recirculated after cooling through a heat exchanger.

As mentioned earlier some lasers are operated in pulse mode only. They are not suitable for CW operation. The reason could be one or both of the following:

- (i) The lower laser level where the laser transition terminates is long-lived compared to the upper laser level. During laser action, this level gets populated and when this population is equal to that of the upper laser level the laser action is self-terminated.
- (ii) The lifetime of the upper laser level is very short, of the order of nanoseconds, which makes continuous pumping very difficult. Population inversion in such lasers is established by high-voltage impulses or high-energy electron beam pulses.

3. Carbon dioxide laser

The CO_2 laser is the most important laser for material processing applications. This is because of its high output power capability and high efficiency. It gives out laser

radiation on several discrete lines between 9 and 10 microns in the infrared region. CO₂ lasers are operated in both CW and pulsed modes. The CW power ranges from a few milliwatts in miniature devices to thousands of watts in large-scale industrial versions. The highest CW power reported so far is 100 kW and there seem to be no limitations for even higher power outputs. The maximum efficiency achieved is nearly 30% in small systems. However, overall efficiencies of large versions are limited to within 10%. In pulse mode operation maximum energy of 100 kJ in a single pulse of one nanosecond duration has been obtained from a CO₂ laser oscillator–amplifier chain, the largest system ever made for laser fusion research. The earlier work on CO₂ laser has been exhaustively reviewed by several authors (Beaulieu 1971; De Maria 1973; Wood 1974).

The carbon dioxide molecule is a linear molecule and has three different modes of vibration around its equilibrium position, as illustrated in figure 2. These are called symmetrical, bending and asymmetrical modes of vibration. The CO₂ molecule can have any quanta of energy in each mode. The vibrational energy state having n_1 , n_2 and n_3 quanta of energy in the above three modes respectively is represented by (n_1, n_2, n_3) . In addition to the vibrational modes, the molecule can rotate around an axis perpendicular to the molecular axis. This gives rise to a large number of closely spaced rotational energy levels associated with each vibrational mode. The infrared radiation in the CO₂ laser originates from the transitions between vibrational rotational levels of CO₂ molecules, as illustrated in the figure.

The excitation is produced usually by passing electrical discharge current through a mixture of CO₂, N₂ and He. In the electric discharge N₂ molecules are excited by direct collisions with electrons and they subsequently selectively excite the upper laser level (001) of CO₂ by collisional energy transfer. This produces population inversion between the (001) state and the (100) and (020) states corresponding to

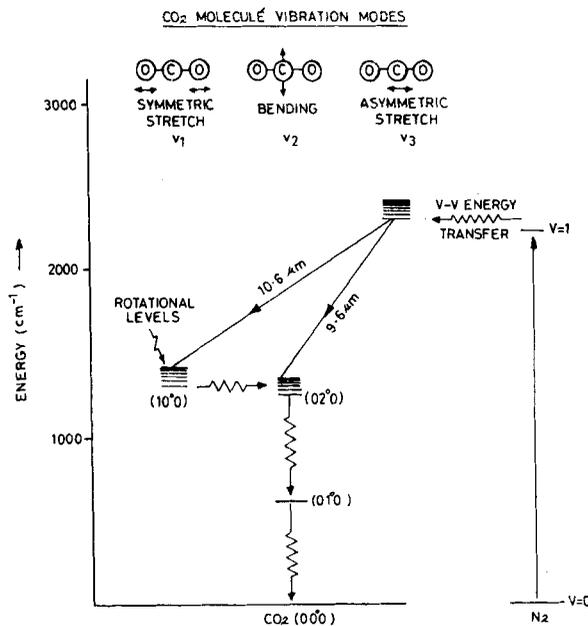


Figure 2. Relevant vibrational energy levels of the CO₂ molecule and laser transitions.

laser transitions at 10.6 micron and 9.6 micron bands respectively (figure 2). The CO_2 molecules in the lower laser levels quickly relax to (010) level by collision with ground-state CO_2 molecules and subsequently come down to ground state by collision with molecules of other gases, releasing the vibrational energy as heat energy. Helium is the most efficient collisional partner for this process and removes heat from the lasing zone to the wall of the discharge tube. The rise in laser gas temperature populates the (010) level which reduces the population inversion and the laser output power. More details about the excitation processes can be found elsewhere (Willett 1974b).

The conventional CW CO_2 lasers are similar in construction (figure 1a). They are excited by either d.c. or r.f. discharge. The optimum composition and pressure of the gas mixture vary widely with the laser design. Typical gas pressure is around 15 torr with CO_2 , N_2 and He in the ratio of 1:1:5 (Willett 1974b). Besides the problem of heat removal from the lasing region the other problem encountered in these lasers is the depletion of CO_2 because of its dissociation in the discharge and formation of other gaseous products which are harmful for laser action. In conventional lasers the heat is diffused out from the lasing region to the discharge tube wall by helium atoms which have high mobility and the tube wall is usually cooled with water made to flow through a jacket around the tube. The other problem is avoided most simply by continuously exhausting the laser gas mixture and replacing it with fresh mixture. However, sealed-off CO_2 lasers have also been developed and are commercially available. Some have operated for many thousands of hours (Newman and Hart 1987). Such lasers incorporate electrode materials which will getter the harmful decomposition products and have a large reservoir of the laser gas mixture. In some cases certain catalysts or some other gases, such as H_2 , water vapour or CO, are used to promote regeneration of CO_2 .

In the power range of 5 to 50 watts, waveguide versions are becoming more popular. These lasers utilize a small-bore diameter (typically between 1 mm and 3 mm) ceramic tube (beryllium oxide or alumina) which acts as a waveguide to contain the lasing volume and guide the laser radiation (Newman and Hart 1987). They can be operated at pressures relatively higher compared to those of conventional systems and therefore large output powers are available from shorter discharge lengths.

3.1 High-power CW CO_2 lasers

In a slow gas flow or sealed-off CO_2 laser, the maximum output power which can be achieved is about 75 watts per metre of active length. This is limited by the rise in laser gas temperature, which is controlled by diffusion processes as mentioned earlier. In such systems the output power can be scaled up by increasing the active medium length. Maximum output power of 8.8 kW was reported from a laser with a total length of 600 ft (Willett 1974b). Laser systems with such large size are not very convenient for the industrial floor. However, the conventional CO_2 laser design is still attractive because of its simplicity and ease of operation. Recently Kozlov and Kuznetsov (1985) designed a multibeam laser system incorporating 37 parallel discharge tubes each of 10 mm diameter and 360 cm active length placed within a common resonator consisting of a pair of plane mirrors, and obtained CW power output of about 4.5 kW.

In recent years, the problem of lower level bottle-necking due to rise in laser gas temperature has been circumvented by fast flow of the laser gas through the discharge zone and its replacement with cool gas. This has yielded high power output in units that are smaller.

3.2 Fast gas transport CO_2 lasers

Various configurations of gas flow have been utilized for high-power CW CO_2 lasers. The most practical configurations, which are used in commercial lasers, are (i) axial flow, (ii) transverse flow, and (iii) helical flow, as schematically shown in figure 3.

In the axial flow system the laser gas flows along the discharge tube axis at a very high speed. Generally the electric discharge that excites the gas is also applied along the tube axis. Like in conventional slow-flow or sealed-off lasers, the gas pressure in a fast axial flow laser is low (30–50 torr) and the tube diameter is also not too large, and therefore the stability and uniformity of the discharge are maintained by diffusion processes. In large diameter tubes the discharge tends to constrict into an arc and this is usually overcome by flowing the gas through narrow nozzles creating a highly turbulent flow. This requires gas circulating pumps which can generate very high pressure heads and large volumetric flow. The axial flow lasers provide better quality laser beam than the transverse flow lasers. Output power per unit length of up to 2–3 kW/m are obtained in this configuration (Sugawara *et al* 1984). More recently, much higher power per unit length has been reported in a modified

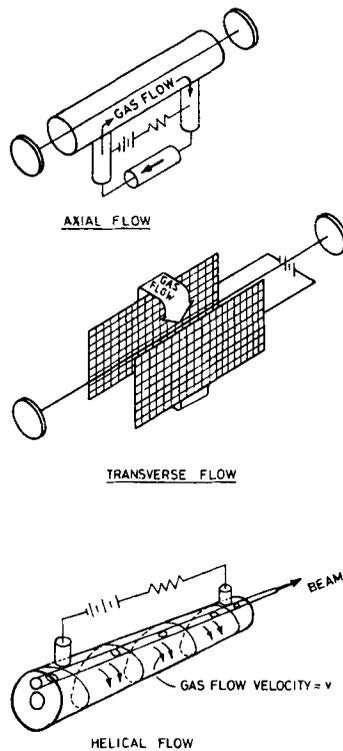


Figure 3. Basic structures of axial flow, transverse flow and helical flow lasers.

version of this configuration. Harry and Evans (1987) have achieved 3.5 kW output power from a 0.6 m active length by using multiple electrodes with gas injection through porous anodes.

In transverse flow lasers the gas flow direction is perpendicular to the axis of the laser cavity, as shown in figure 3. The electric field that pumps the laser is usually orthogonal to both gas flow direction and optic axis. This configuration is more suitable for exciting large laser gas volumes compared to the axial flow system. However, transverse flow lasers require specially designed discharge electrodes such as resistively ballasted multiple-pin or segmented electrodes for maintaining uniform discharge (Reilly 1976). In addition to this many lasers incorporate one of several auxiliary schemes, such as electron beam, r.f. discharge, high voltage, high repetition rate pulses, or corona discharge superimposed on d.c. in order to maintain uniform discharge in a large volume at high input electrical power densities (Reilly 1976). The output power per unit length from these lasers is in the range of 8–10 kW/m (Elov *et al* 1982).

The helical gas flow configuration (Yessik and Macken 1983) is a variation of the transverse flow system in that the laser beam and the electric discharge are arranged colinearly. But here the gas flows in a helical path, alternately entering the active region where it participates in the lasing process and gets heated and then entering a heat exchanger where it is cooled, prior to the next cycle. This helix continues down the length of the laser (figure 3). This technique duplicates the effect of a cross-flow configuration, but the pump capacity required is reduced by a factor equal to the number of revolutions of the helix. In this configuration, the laser output power per metre of discharge length is enhanced by several-fold over that of the axial flow system.

3.3 *Transversely excited atmospheric pressure (TEA) pulsed CO₂ laser*

Carbon dioxide lasers have been operated at high pressures in the range of atmospheric pressure in pulsed mode and output energy of several joules in a pulse of duration of the order of a microsecond has been obtained. At these pressures the electric discharge degenerates into an arc. Therefore high-pressure CO₂ lasers are usually operated in pulse mode. These lasers are excited by transverse discharge in that the excitation field is normal to the optic axis (figure 1b). This configuration has several advantages over axial excitation, as discussed earlier. The transversely excited atmospheric pressure lasers have come to be known as TEA lasers.

In order to establish uniform electric discharge in large volume at high input energy loading several schemes were developed, such as ballast resistance TEA CO₂ laser, u.v. preionized laser, corona-initiated discharge laser, electron beam sustained laser, etc. (Willett 1974b). These methods are shown schematically in figure 4. The typical output energy from a TEA CO₂ laser is in the range of 10 J per litre of the active volume. The output laser pulse has usually an initial spike of 100–500 nanoseconds and a long tail of 1–5 microseconds.

The CO₂ laser normally oscillates on one rotational line, the P (20) line of the 10.6 micron band, which has the highest gain. With the help of a grating in place of one of the cavity mirrors the output can be easily tuned on a large number of rotational lines of 10.6 micron and 9.6 micron bands. For certain applications where simultaneous oscillation of more than one rotational line is desired, for

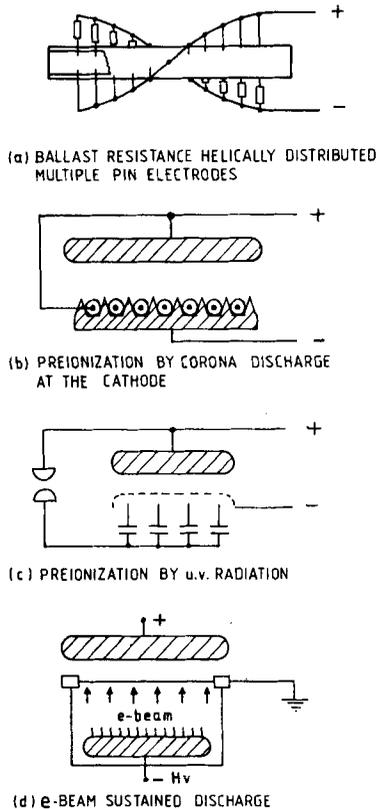


Figure 4. Various electric discharge systems for pumping TEA CO₂ laser.

example in efficient extraction of laser energy from a CO₂ laser amplifier in time duration comparable to rotational relaxation time (0.2 nsec at atmospheric pressure), or in multiphoton excitation and dissociation processes, multi-rotational-line oscillation is obtained by different techniques such as by incorporating frequency dependent intracavity losses (Piltch 1973). In one of the simple schemes hot CO₂ was used as an intracavity absorber and simultaneous laser oscillation on four rotational lines were obtained (Nath and Chatterjee 1980).

High-power CW CO₂ lasers have also been excited by gas dynamic process and chemical pumping, and continuous output power of more than 100 kW has been obtained. However, these types of CO₂ lasers are not common in industrial applications.

4. Argon-ion laser

The argon-ion laser is the most common type of ion laser and has wide-ranging applications in a variety of fields, as indicated in table 1. This can lase on a number of transitions in the visible and ultraviolet regions of the spectrum. The strongest transitions are at 4880 Å and 5154 Å. A partial energy level diagram relevant to the laser transitions is shown in figure 5. These energy levels are the levels of the Ar ion. Therefore, in order to operate an Ar-ion laser, the atoms must first be singly ionized and then excited. The ground state of the Ar ion lies almost 16 eV above the ground state of the neutral Ar atom. In addition, the upper laser levels lie approximately

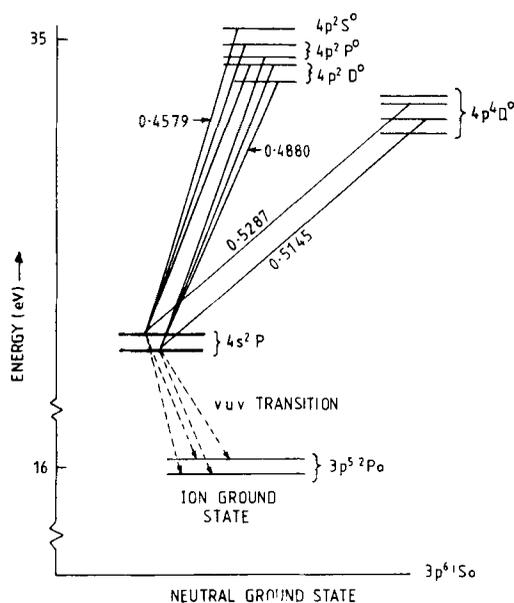


Figure 5. Energy level diagram of the singly ionized argon ion relevant to the operation of the argon-ion laser. The laser wavelengths are shown in microns.

20 eV above the ionic ground state. Thus a considerable amount of energy must be supplied to the neutral Ar atom to raise it to the upper laser level of the Ar ion.

The Ar-ion laser has been operated in pulsed as well as in CW modes. In short pulse mode operation, the upper laser level is populated by mainly single-step excitation process through direct collision with high-energy electrons in a pulse discharge. In pulse mode operation with long discharge current durations and in CW mode operation, the laser excitation is mainly by two-step electron collision process. In this, the output power scales nonlinearly with the current density, so it is desirable to operate the Ar-ion laser in a narrow-bore tube at a high current. Current density in the range of 100 A/cm^2 is used. The high current density produces heating and has significant effects on the construction of these lasers. The laser tube requires high temperature materials. The commonly used materials include quartz, graphite or beryllium oxide. Beryllium oxide, which has high thermal conductivity, is also particularly good as it withstands the eroding effects of the electric discharge.

A magnetic field, parallel to the laser axis, is commonly used in the CW Ar-ion laser. The main effect of the magnetic field is to increase the electron density in the discharge plasma by constraining the electrons to move in a helical path around the magnetic field lines. This prevents the loss of electrons to the tube walls.

The maximum output power reported from an Ar-ion laser is 150 W but commercial models are available in the range of 2 W to 15 W. The total output power is usually specified as the sum of the powers for all the different lasing wavelengths. Single-line operation on one of the wavelengths may be obtained through the use of a prism in the laser cavity, which of course will reduce the output power. Readers are referred to the article by Willett (1974a) for more details on Ar-ion lasers.

5. Excimer lasers

Another class of lasers that has attracted a lot of interest in recent times are the excimer lasers. They are the most efficient (greater than 1%) lasers giving out laser radiation in the ultraviolet and vacuum ultraviolet ($0.1 < \lambda < 0.4 \mu\text{m}$) region of the spectrum and are potentially scalable to high average output power in the range of kilowatts. Molecules which are bound (atoms attracted to each other, and forming a stable molecule) in an excited state, but which dissociate, or are weakly bound, in their ground state, are known as excimers. The laser transitions are between the bound, excited levels and the dissociative ground level (figure 6). Following the stimulated emission of radiation the molecules dissociate rapidly, avoiding the problems of lower laser level bottlenecks.

Since the first demonstration of an excimer laser in Xe_2 by Basov *et al* (1971), laser emission was obtained in several excimers of the rare gases (Xe, Kr, Ar), their oxides (XeO , KrO and ArO) and rare gas monohalides (XeF , XeCl , XeBr , XeI , ArF , KrF , etc.), covering the 126 nm to 558 nm spectral range.

Among these different types of excimer lasers the rare gas halide lasers have yielded the best performance to date. For example, single pulse energies of about 100 J were reported for a KrF laser with medium efficiency of up to 15% (Ewing and Brau 1975; Hoffman *et al* 1976). Commercial versions of these lasers are available in the average power range of 50–100 W operating at repetition rates of 100–500 Hz.

The bound-to-free transitions on which excimer lasers operate have large spectral width. Since the stimulated emission cross-section is inversely proportional to the spectral width of the transition, the excimer lasers have inherently small stimulated emission cross-sections. This makes large excited-state populations necessary for reasonable gain. Moreover, the lifetimes of the excimer molecules in the upper level are very small, of the order of a few nanoseconds, and therefore these lasers require very intense pumping for creating a reasonable population size in the upper laser level. This has been feasible only in pulse mode using intense excitation by electron beam and fast electric discharge.

5.1 Production mechanisms of excimers in the upper laser level

In excimer laser, the excitation mechanism of the upper laser level has to be indirect

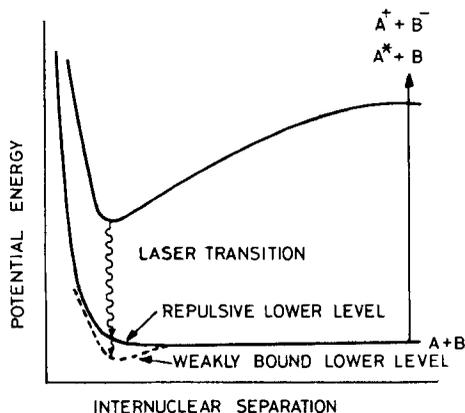
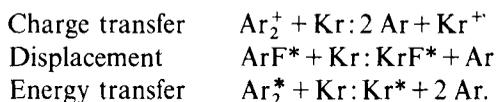


Figure 6. Partial energy levels of excimer lasers.

chain in Kr are the following:



The lifetimes of various intermediate states and the reaction cross-sections of cross-links are such that the probability of KrF^* formation is very high. In a gas mixture of 93.5% Ar, 6% Kr and 0.3% F_2 with a total pressure of 1 atm excited by a high-energy electron beam, as much as 30% of the pumping beam energy results in the production of KrF^* excited state molecules (Holzrichter *et al* 1982).

In practice, rare gas excimer lasers are operated at several hundred psi pressure and pumped by pulsed electron beam of energy 0.2–2 MeV and current 1–10 kA. The rare gas halide excimer lasers have been pumped by fast electric discharge and electron beam. The technology is quite similar to that of TEA CO_2 laser (figure 4). However, the requirements for excimer lasers are usually more stringent. Compared to the CO_2 laser, the electron beam energy and current required for excimer lasers are very high. In electric discharge excimer lasers, the tendency of the discharge to degenerate into an arc is very high. Therefore the discharge circuitry for the excimer lasers should be of very low inductance to allow the discharge voltage pulse to rise in a very short time (1–10 kV/nanosecond) and prevent local instabilities from occurring (Mace 1981).

Since the excited state lifetime is very small ($6\text{--}8 \times 10^{-9}$ s), excimer lasers are suitable for generating and amplifying laser pulses of very short duration. One of the uses of the high energy level activity of KrF^* excimer laser is in fusion studies. Total amplified output of 100 kJ and overall wall-plug to optical output amplifier efficiency of 8% appear feasible (Holzrichter *et al* 1982). The recent impetus for developing high average power excimer lasers is because of their potential applications in photochemistry, pumping dye lasers, medical treatments, material processing particularly for semiconductor industry and photolithography.

6. Conclusions

In conclusion, we have briefly described the excitation mechanisms and design concepts of CO_2 , Ar-ion and excimer lasers, which are commonly used in material processing. The technologies of CO_2 laser and Ar-ion laser have come to sufficient maturity, while the requirements in excimer lasers are more stringent compared to other lasers. Owing to their lasing activity in the uv region of the spectrum, high efficiencies and potential applications in a variety of fields including microelectronics, excimer lasers have attracted world-wide attention and are gradually gaining commercial acceptance.

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