Excimer Lasers

A dimer refers to the association of two like molecules (or atoms) say M to form M_2. An excited dimer is similar but is bound only in an excited state forming a pseudo molecule i.e. M_2*, and on losing this excitation dissociates as following:

$$M_2^* \rightarrow M + M$$

If two dissimilar molecules or atoms M and N are bound as MN* in the similar way the system is termed an *exciplex* (excited complex). The majority of excimer lasers available commercially are based on dissimilar atoms, and as such should be called exciplexes. However, the term 'exciplex' is not commonly used, so we group them together as excimers (excited dimers).

The upper state is bound for a sufficiently long time so that the population can build up easily, whereas a repulsive (or dissociative) lower state will have near-zero population because of its very short lifetime. A schematic energy level diagram for an excimer laser illustrating an optical transition from the associative upper bound state MN* to a repulsive lower (ground) state M + N is shown in Figure 1. The curve of potential energy for the excited state touches a minimum suggesting the molecule MN can exist in the excited state as pseudo molecule. This transition

$$\mathbf{MN}^* \rightarrow \boldsymbol{M} + \boldsymbol{N} + \boldsymbol{Photon}$$

can have a broad emission line width as no well-defined vibration states exist for the lower level.

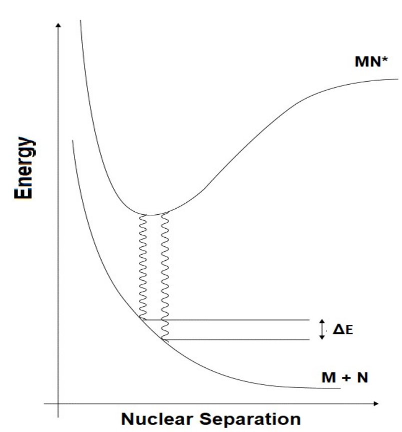

Figure 1

https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/excimer-laser

The rare gases are characterized by highly low level of reactivity in their ground state, but in an excited state they behave chemically as though they were in the alkali metal group as they have one electron in the outermost shell. So an excited Ne will become Ne* and act as Na in a chemical reaction. In the same way, Ar* will act as K, Kr* will act like rubidium and Xenon as caesium. Reaction with halogens then proceeds vigorously, resulting in the formation of short-lived pseudo compounds that are ionically bonded when in the excited state.

Let us take argon fluoride (ArF) as an example. This laser uses a F_2, Ar, He (Ne) mixture. The following basic reactions are supposed to occur:

$e + Ar \rightarrow Ar^+ + 2e$ electron collision ionisation

$e + Ar \rightarrow Ar^* + e$ electron collision excitation

$e + F_2 \rightarrow F^- + F$ dissociative attachment

Excimers may be formed from these species by two main routes:

1. The neutral route

$$Ar^* + F_2 \rightarrow ArF^* + F$$

2. The ion route, involves

$$Ar^+ + F^- + \mathbf{A} \rightarrow ArF^* + \mathbf{A}$$

Here, the third body **A** (usually He or Ne) is the high-pressure buffer gas component in the mixture. It helps balance energy and momentum in the reaction. The buffer gas also helps increase the heat capacity of the system so that the discharge-induced temperature rise is constrained.

Population inversion in ArF* is created between the bound upper state and the repulsive ground state, which are connected by a strong UV radiative transition centred at 193 nm with a radiative lifetime of 4.2 ns. On emission of a photon as per following reaction:

$$ArF^* \rightarrow Ar + F + h\nu$$

the binding excitation is lost. ArF* is also cooled to ground state by collisions as per the following reaction:

$$ArF^* + A \rightarrow Ar + F + A$$

which, together with radiative loss, reduce the upper state lifetime to a few nanoseconds. If a volume of eximers is created in an amplifying medium, lasing may take place through transition between the upper associative state and lower dissociative state. After undergoing laser transition the molecules reach the repelling ground state, they dissociate quickly.

Excimer lasers are pulsed lasers of short duration. These lasers are made by combining a rare gas atom of argon, crypton, xenon, etc. and a halogen atom of fluorine, chlorine, bromine or iodine. An excimer laser generally emits in the ultra violet region of the spectrum. Some of them may also operate in the visible region. Examples of excimer lasers are;

Ar_2 with transition at 126 nm
Kr_2 with transition at 146 nm
F_2 with transition at 153 nm.
Ar-F with transition at 193 nm
Kr-Cl with transition at 222 nm
Kr-F with transition at 248 nm
Xe-Cl with transition at 308 nm
Xe-F with transition at 353 nm

A Kr-F excimer laser operates with total gas pressure of 2 atm; having partial pressures of F_2 10 (torr), Ar (30 torr) and He (1400 torr). The pulsed output has duration of 10-50 ns with pulse energy of 0.1 to 1.0 J. The pulse repetition rate can be up to several hundred hertz. The maximum output has a narrow width of 0.3 nm.

An excimer laser generally has a gain medium of length 0.5 to 1.0 m. The halogen species have a tendency to disintegrate and form other unwanted compounds during the laser operation. Hence, the arrangement for re-circulation of the gas is made for supply of pure constituents of the gases in the amplifying medium. The muti-mode gains in these lasers are high. As halogens are corrosive in nature the entire structure and components are made of stainless steel with corrosion resistant material such as Teflon. The discharge takes place in the transverse direction. The electrodes are metal pieces that are flat and long in size. The metal pieces are rounded for uniformity of electric field when the voltage is applied. Thus arc discharge is avoided and there is uniform discharge. The initial electron seeding is achieved through pre ionization pulse, produced by an array of tiny ultraviolet spark charges called flash board.

These sparks produce sufficient ultra violet radiation to produce ionization in the gain region which substantially increases the electrical conductivity of the gain medium. A high voltage capacitor, coupled with a thyratron-switching device produces the discharge current. A mirror with high reflectivity is placed at the rear of the arrangement. A flat quartz is placed at the output coupling mirror. The low reflectivity of the quartz is adequate to give the required optical feedback. Figure 2 shows one such schematic diagram of a commercial Excimer laser.

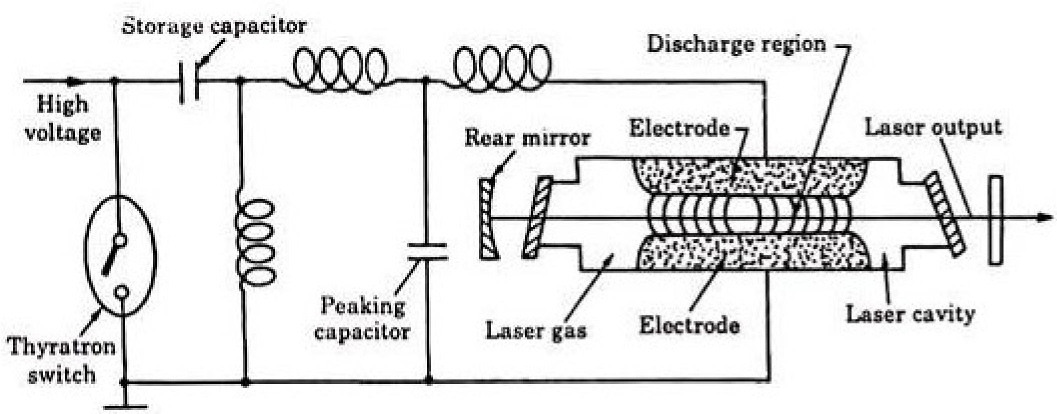

Figure 2

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Applications:

1. Medical uses: The UV light from an excimer laser is well absorbed by biological matter and organic compounds. The excimer laser adds sufficient energy to disrupt the molecular bonds of the surface tissue without burning them. This allows tissues to disintegrate into the air in a controlled operation, the ablation. Thus excimer lasers can remove very fine layers of surface material with almost no heating or change to the remainder of the material. This property makes

excimer lasers well suited to precision micromachining organic material, or delicate surgeries such as eye surgery LASIK.

2. Photolithography: Excimer lasers are widely used in high-resolution photolithography machines for microelectronic chip manufacturing. Current state-of-the-art lithography tools use deep ultraviolet (DUV) light from the KrF and ArF excimer lasers with wavelengths of 248 and 193 nanometers. Excimer laser lithography has played a critical role in the continued advance of the so-called Moore's law.
3. Scientific research: Excimer lasers are used in many fields of scientific research, both as primary sources and as pump sources for tunable dye lasers, mainly to excite laser dyes emitting in the blue-green region of the spectrum.

Excimer lasers are facing strong competition from solid-state lasers, although they still offer the most efficient access to the ultraviolet spectral region—with high energies, and high peak and average powers in pulsed operation. However, they have some drawbacks, such as poor beam quality (higher-mode structure and high divergence), their size, operating costs, and maintenance requirements.