

Laser Technology in the Medical and Cosmetic Industry

Abstract: This paper and discusses the use of Lasers and similar technologies (such as Intense Pulsed Light) in the Medical and Cosmetic Industry. Their theory of operation is detailed along with their power requirements (which vary for different types of laser technologies). Finally, power solutions to specific applications that utilise Excelsys products are described.

1.0 What is a Laser:

To answer the question what is a Laser, we must first consider what light is. Light is electromagnetic radiation (fluctuations of the electro and magnetic fields) which can transfer energy from one location to another. White light such as sunlight or the light from an ordinary bulb is actually made up of many different light rays that have different wavelengths, phases and directions that all mix together to form white light, but also result very diffuse energy transfer. This is known as *incoherent light*.

A Laser is an example of *coherent light*, which is light of a single wavelength (which means a single colour), and whose waveforms are all in step, or in phase. Coherent light can be focused in a very small area and at a very high intensity. At a high enough intensity this Laser Light can be used to cut (essentially vaporise) or weld materials by means of superheating. At lower intensity levels lasers can be used to heat localised areas such as hair follicles, tattoos or melanin, which are broken up and then reabsorbed by the body.

This ability to superheat, cut, weld (or cauterize tissue) means that lasers can be used in a wide range of medical and cosmetic applications including (but not limited to):

Cosmetic Procedures

The localised heating ability of Lasers can be used to breakup tattoos, birthmarks and sunspots or can be used to remove hairs or whiten teeth. Lasers are also used to treat scars, stretch marks, wrinkles or spider veins by making tiny “micro-cuts” which then promotes collagen formation.

Surgery

Lasers are used in eye surgery (to reshape or repair the cornea of the eye to improve vision), cataract removal, dental surgery, tumour removal, breast surgery, plastic surgery (etc).

Other Applications

Other medical applications include medical imaging, microscopy, lithotripsy and diagnostic applications.

2.0 How do Lasers Work?

All lasers are made up of three parts:

1. A pump source (or external power source)
2. A gain medium (or laser medium)
3. An optical resonator

Pump Source

The pump source is used to deliver energy to the gain medium. There are many types of pump sources including electrical discharge, electric current, flashlamps, arc lamps, light from another laser, chemical reactions and even explosive devices. The choice of pump source is generally dictated by the gain medium being used.

Whether the laser is pulsed or continuous wave (CW) can also impact the choice of pump source. For example, flashlamps are pulsed, while an arc lamp is CW.

Gain Medium

The atoms in the gain medium absorb energy from the pump source and this results in the emission of light (photons) at a wavelength that is determined by the type of gain medium used.

Types of gain media include liquids (dyes), gases (carbon dioxide, argon etc.), solids (crystals, glasses) and semiconductors.

Optical Resonator

The optical resonator keeps photons inside the gain medium which results in amplification of the Laser light, and focuses the laser energy into a narrow beam. The simplest form of optical resonator is two mirrors placed around the medium with a small hole in one to focus the Laser beam.

3.0 Laser Example - Red Laser

As an example of a laser design, we will look at the first laser ever invented, the ruby laser.

As previously discussed, the ruby laser is made up of a pump source (a flashlamp), a gain medium (a ruby crystal) and an optical resonator (two mirrors).

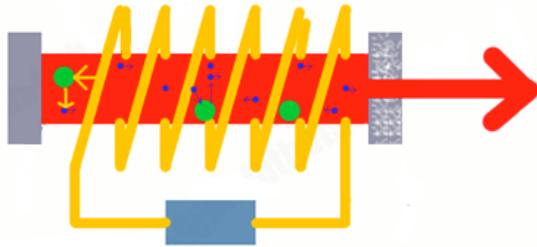


Figure 1. Ruby Laser

A high voltage power supply is used to power the flashlamp, which flashes with an intense, incoherent light. These flashes “pump” energy into the ruby crystal gain medium. Atoms in the ruby absorb this energy, become excited and spontaneously emit photons which travel up and down the gain medium, reflected at each end by the gain medium. These photons hit other atoms that are already excited, and they give off two photons (stimulated emission). The light in the gain medium has now been amplified. This is where the name “Laser” comes from, an acronym for Light Amplification by Stimulated Electromagnetic Radiation.

A mirror at one end of the ruby crystal continues to reflect the photons back into the gain medium to continue the light amplification. Another mirror at the opposite end of the ruby crystal has the same function, but this mirror has a small hole in it and allows some light to escape. This results in a narrow, powerful beam of powerful laser light.

4.0 Other Laser Technologies

The Ruby red laser was invented in the 60’s, but in the following years many other lasers were invented using different gain media.

Solid and Liquid Lasers

The Ruby Laser is an example of a solid laser, where a glass or crystal gain medium is excited by a flashlamp (as described above) or by another laser (like a diode laser) in place of the flashlamp. Using a different gain medium results in a Laser light of a different wavelength.

Liquid lasers are made up of organic compounds (or dyes) that been dissolved in solvents such as alcohol and water. Lasing has been observed in a wide range of organic dyes, and even dyes that are colourless may absorb light and emit in the visible, ultra-violet and near infra-red spectra. Dye lasers are again pumped by flashlamps or other lasers.

The most exciting feature of dye lasers is the ability to “tune” the output wavelength over the entire visible spectrum from ultra-violet to infra-red. This

is achieved by mixing several dyes together to form the gain medium. The ability to deliver tunable, coherent light is extremely useful in the fields of spectroscopy and in biomedical applications.

Gas Lasers

In Gas Lasers, the gain medium is a gas at a very low pressure (a few milli-torr), and the pump source is a power supply designed to provide an electric discharge. Collisions between the electrons in the electric discharge and the gas molecules produce the photons in this Laser. The gas is at such a low pressure to allow an electric discharge over a long path (provided by a long tube with electrodes at both ends). Most elements can be made to lase when in the gas state.

The electrical discharge in a gas is generally characterised by the voltage / current curve shown below (with the actual voltage and current values dictated by the nature of the gas, its pressure and the length and diameter of the gain medium).

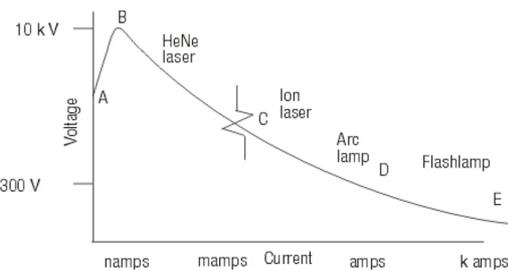


Figure 2. Current/Voltage Curve for Gas Discharge Lasers

At low voltages, there is no current flow. As the voltage is increased, a voltage is eventually reached where a small amount of current flows (prebreakdown current) due to a small amount of ionisation that is always present due to natural radioactivity and cosmic rays.

As voltage increases further, current slowly increases until a point where a large number of molecules are ionised (the peak of curve). Now the conductivity of the gas increases and the voltage required to sustain discharge decreases with increasing current (negative resistance). Current control (possibly in the form of a ballast resistor) is required to prevent this rapid increase of current.

The basic design of a DC supply pump source for a Gas Laser is the same whatever Gas is being pumped (although the voltage-current requirements will depend upon the Gas choice and the Laser configuration - length of tube etc). Three essential elements are required:

- Starter or ignition circuit - Provides the initial pulse to drive past the breakdown voltage of the gas
- Operating supply - Provides steady voltage to the gas to sustain current flow
- Current limiting element - Prevent uncontrolled current rise through the gas.

Some examples of DC breakdown voltage are as follows:

- Helium Neon: 10 kV breakdown voltage, 2-4 kV to maintain
- Argon Ion: 6-8 kV breakdown voltage, few hundred volts to maintain
- Nitrogen: 15 40 kV breakdown voltage
- Krypton: 2-3 kV breakdown voltage, 90 – 400 V to maintain
- Helium Cadmium: 10 kV breakdown voltage, 700 – 2 kV to maintain
- CO2 Laser: 3 kV breakdown

What is obvious is that these voltages are far too high for an Excelsys supply to provide. An alternative option is to use RF excitation of the Gas Laser. This only requires tens of volts as opposed to the thousands of volts required by direct excitation. Reviewing laser manufacturer's requirements for DC power supplies for RF systems shows a wide variety of voltage and current requirements.

This can be an advantage for Excelsys, as the modular concept leads itself to platform designs where the voltage and current requirements may change, but performance will be maintained. When choosing a supply, it is recommended to consider rated ripple current under load, tight voltage regulation and the ability to set the output voltage. Also, the supply should be able to withstand rapid high current peak requirements.

Semiconductor Lasers

Laser diodes (semiconductor lasers) are simply diodes, and must be Current driven like any diode (due to the very steep diode V-I curve). If driven correctly, they are very reliable with long lifetimes (the light emitted slowly with age as opposed to catastrophic failure).

A laser diode supply should include:

- Soft Start (to prevent overshoot that can damage laser diodes)
- Current regulation
- Transient suppression (again to prevent damage due to excessive current)
- Capability for modulation

The voltage and current requirements of semiconductor diodes are much more modest than compared to other laser devices (the voltage appearing across a diode laser is around 2-3 V, with currents as low as milliamperes). These diodes can be stacked in parallel or in series to increase voltage/current and power. Semiconductor lasers are generally more efficient than other laser types.

5.0 Similar Technologies

Flashlamps (IPL)

Flashlamps operate in a similar fashion to Gas lasers, and are pulsed in order to emit incoherent light (not at a single wavelength like lasers). They are in the form of linear or helical quartz envelopes with circular cross section with electrodes at each end. The lamp is filled with gas (typically Xenon) to a pressure of 300 to 700 torr. The power supply for flashlamps usually consists of

- A high voltage cap charging supply (the capacitor must be charged fully between pulses)
- A large capacitance
- A pulse forming network (inductor, resistor and capacitor)
- A trigger circuit

An example is shown below:

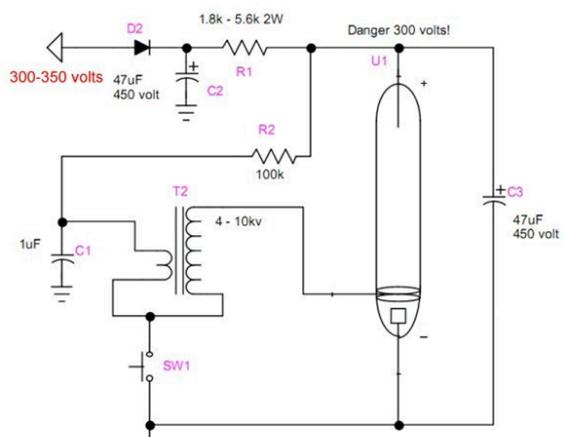


Figure 3. Flashlamp Circuit

The stages of a flashlamp pulse is as follows:

Triggering and Initial Arc Formation

Triggering of a flashlamp is the formation of a spark streamer that crosses the gap in the electrodes and initiates the discharge. This is done with a secondary high voltage circuit (trigger circuit) that generates a very high voltage pulse.

Unconfined Discharge

Just after triggering, the resistance of the gas is still very high and the discharge is still a “streamer” that is undergoing expansion (lamp is still not filled). As the capacitance and pulse formation network continues to supply current to the lamp, the resistance of the gas falls and the streamer grows until it fills the tube. (This expansion takes about 5 – 50 us and depends on the current and voltage available from the capacitor).

Wallstabilized Operation at High Current

Now the streamer (or plasma) has filled the tube, and is stabilized by the wall. This stage encompasses most of the duration of the pulse, and during this stage a very large current flows. This current is controlled by the supply, and a pulse formation network.

Flashlamps are widely used as pump sources for other lasers (such as Dye lasers and solid state lasers).

The relatively wide spectrum light (compared to Lasers) from a flashlamp is also used in skin treatments including hair removal, photorejuvenation and acne treatment (known as IPL or Intense Pulsed Light Therapy). The use of broad spectrum light means that IPL can be used to treat many conditions, whereas single wavelength lasers typically only target one condition.

RF

The same technology that can be used to drive gas lasers, it is often used in conjunction with lasers in a clinical setting. Cosmetic RF treatment uses RF energy in short pulses that oscillate through the skin, and is used to heat targeted tissue. RF is used to tighten skin by penetrating the skin and stimulating the contraction of collagen and the production of new collagen.

6.0 Excelsys Supplies as Pump or Energy Sources for Pump Sources

Flashlamps

The DC power supply requirement for a flashlamp is essentially a cap charger.

A capacitor is a passive device that stores energy in its electric field. It is made up of two conducting plates separated by an insulating material or dielectric. During the charging process, electrons flow from the negative terminal of the power supply to one plate of the capacitor and from the other plate to the positive terminal of the power supply.

If charging with a constant voltage, when the switch is closed and charging starts, the rate of flow of charge is large (i.e. resulting in a large inrush current) and this decreases as time goes by and the plates become more charged so "resisting" any further charge. This current can overload and damage the supply.

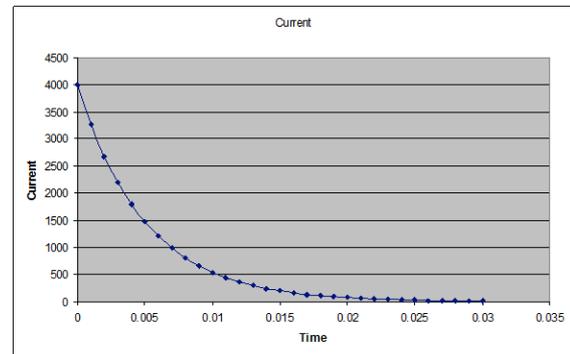


Figure 4. Charging Capacitance with Constant Voltage

A better, more controlled charge method is to use a constant current. This results in a controlled (but slow) linear voltage rise:

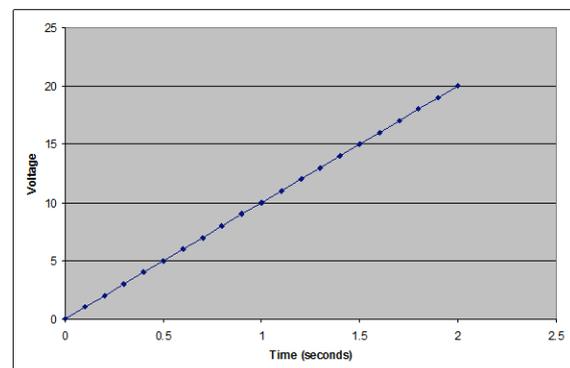


Figure 5. Charging Capacitance with a Constant Current

The Ultimod has a current limit protection circuit that makes the supply act as a constant current source when charging a large capacitance.

The Ultimod modules also incorporate short circuit protection that causes a hiccup when a short circuit is detected, and switching into a discharged capacitor is very similar to switching into a short circuit!

Short circuit protection on the Ultimod modules work by monitoring the output voltage at regular intervals. If the output is below a certain threshold (which is different for different modules), the output will shut down, and then try to start again after a set “off” time period. This is hiccupping.

So, the hiccup times (which are set by an RC network) are as follows:

- After startup, 20 ms “on” time.
- If the voltage is not above the SCP threshold, 45 ms “off” time, followed by a 10 ms “on” time.
- The 10 ms “on” and 45 ms “off” is then repeated until the threshold voltage is reached.

So, what does that mean for the Ultimod? The Xg4 threshold is set at 6.8 V, so we will expect to see hiccupping until the capacitor is charged to that voltage. As we have seen previously, charging with a constant current slows voltage rise, and if large enough it is very possible that the voltage will not reach 6.8 V in 20 ms! To reduce this issue, widetrim modules (whose short circuit protection is reduced to 1 V) should be used. Also, to prevent any reverse EMF issues, an external blocking solution should be used (or wide trim XgT modules.....).

The questions we need to know when using the Ultimod to charge a capacitance is:

- How large is the capacitance
- What is the operating voltage
- Is there additional loading
- Is there a time limit for this charge
- How far does the voltage dip during discharge
- What is the current drain during discharge
- What is the energy requirement during discharge
- How long do we have for recharge
- Is there an additional load during recharge

With this information known, we should be able to make a recommendation to charge any capacitance.

RF Power Supplies

This has been discussed earlier in this paper, and the Ultimods features of low rated ripple current under load, tight voltage regulation, the ability to set the output voltage and ability to withstand high peak currents make the Ultimod an excellent solution for RF.

Direct Excitation

The current controllability of the Ultimod modules (Itrim function) mean that they are very suitable for use in direct excitation (diode lasers) where important features include:

- Constant current control (may need to remove protective diode from Itrim circuit to improve accuracy)
- Wide trim range
- Low overshoot

- Good transient performance
- Vtrim control (to prevent excessive transients)
- Ability to modulate the current output

7.0 Summary

Excelsys power supplies are an excellent solution for many laser pumping applications, particularly in the medical and cosmetic industries (industrial applications generally require more power and higher voltages, often to drive gas lasers).

The modularity and stability and current control functionality of Excelsys supplies mean that the direct driving of stacks of Semiconductor Lasers are possible, while the low short circuit protection capabilities, again coupled with current limiting allows the powering of flashlamps, whether for direct treatment (IPL) or for optical pumping of other gain media such as liquid or solid Lasers.

Finally, even though direct excitation of Gas Lasers is not possible due to the high voltages required, driving RF amplifiers for RF amplification of low power Gas Lasers is.

8.0 References

Understanding Xenon Flash Tube Circuits:

<http://www.bristolwatch.com/ele/>

How do Lasers Work?:

<http://www.explainthatstuff.com/lasers.html>

Gas Laser Power Supplies:

http://pe2bz.philpem.me.uk/Lights/-%20Laser/Info-902-LaserCourse/c04-02/mod04_02.htm

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