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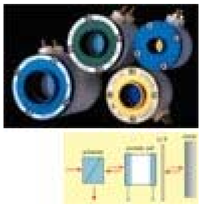
Q-switches deliver powerful pulses

Need powerful pulses from your free-running laser? Then purchasing a Q-switch could be the answer. Rob Swain and Robert Eckardt describe the options available.

From Opto & Laser Europe January 2005

In many applications, it is desirable to have a laser that emits a series of short, high-energy pulses rather than a continuous-wave beam. One of the easiest ways to obtain this pulsed operation is to place a device called a Q-switch into the laser cavity.

So what exactly is a Q-switch? Put simply, it's like a camera shutter - a light-valve that can be switched on and off. An ideal Q-switch has zero loss in its "off" state and infinite loss in its "on" state, and can switch rapidly between these two states.


Q-switches & Fig 1.

The term Q-switch derives from the quality factor or "Q" of a laser resonator which relates to the cavity loss. In order for a resonator to lase, the gain provided by the optical medium, such as a pumped Nd:YAG crystal, must be sufficient to overcome the cavity loss. When a Q-switch is turned on, the cavity loss is large enough (low Q) to inhibit lasing, despite continual pumping of the gain medium. When the Q-switch is turned off, the Q of the cavity is restored and all of the energy stored in the gain medium is released in a single high-power laser pulse. By repeating this process, a train of laser pulses is emitted.

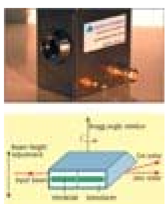
In general, most Q-switched lasers are solid-state, with the highest proportion operating at a wavelength of around 1 µm to coincide with Nd:YAG lasers. That said, frequency conversion is possible after Q-switching to give a high-power visible or UV beam. Pulse widths are typically in the region of 1 ms to 1 ns, with repetition rates of a few hertz up to several hundred kilohertz.

Q-switched lasers are often required when the energy delivered to a target is of importance. This leads to a diverse range of applications including: materials processing (marking, cutting, welding, drilling), medical (ophthalmology and dermatology), military (sensing, rangefinding, target illumination) and scientific research. One particularly widespread use is that of industrial laser marking, where laser pulses are used to create convenient permanent marks without the need for ink.

There are broadly four different flavours of Q-switch: acousto-optic, electro-optic, passive and mechanical. Each has distinctive qualities and advantages as outlined below.

Acousto-optic Q-switch

This is probably the most common type of Q-switch in use today. A radio-frequency (RF) transducer generates an acoustic (ultrasonic) wave within an interaction material. This results in a periodic change of refractive index in the material and the creation of a diffraction grating.



Acousto-optic Q-switch & Fig 2.

Light incident on the Q-switch at the Bragg angle is diffracted, producing a loss in the laser resonator. If the loss introduced by the Q-switch is higher than the gain, then lasing ceases. Switching off the RF drive power to the transducer causes the acoustic wave to decay and lasing recommences with a high-energy pulse.

Choosing the correct AO Q-switch for any given laser can sometimes be a daunting process to the uninitiated. Since good manufacturers not only cater for an extensive range of resonator designs with their "standard products", but also offer custom design solutions, the possibilities are almost endless. Key parameters to consider are wavelength, optical power density, polarization, beam diameter, size constraints and mechanical configuration and cooling possibilities.

• **Wavelength.** Standard wavelengths of 1030-1064 nm, 1340 nm and 2050 nm are most often covered with standard antireflection (AR) "V" coatings. "W" coatings or Brewster-angled optics can be employed where an extended range is required. Historically, Brewster-angled devices were sometimes selected where extremely low insertion-loss was important. However, with today's high-performance coatings, the advantage is negligible and far outweighed by the difficult alignment needed.

• **Materials and optical power density.** Although there are numerous acousto-optic interaction materials, some of the higher-efficiency choices are limited by their laser damage threshold. Q-switch applications are essentially high power and this makes laser damage a critical parameter. For the majority of applications (particularly in the 1 μm range), the material of choice is narrowed to tellurium dioxide for low power, crystal quartz for medium power and fused silica for high power. Nevertheless, the lower cost of manufacture and excellent optical characteristics of fused silica make it a popular choice for all power levels.

• **Polarization.** The acousto-optic interaction is generally polarization-dependant. It is important to specify the laser's polarization.

• **Beam diameter.** For a fixed interaction length, the RF drive power requirement is directly proportional to the height of the active aperture. Hence, in the interest of minimizing RF power, it is important to keep this dimension as small as possible without constraining the interaction. If the beam diameter is larger than the active aperture, leakage can cause problems such as pulse-to-pulse instability. It is also important to consider alignment capability. If you choose an active aperture height very close to the beam diameter, alignment will be more critical.

• **Cooling.** Cooling needs are determined by the RF drive power, which is in turn determined by factors such as beam diameter, polarization state and interaction medium. In low-to-medium-power applications, conductive cooling is sufficient. For most medium-to-high-power applications where the laser is unpolarized, RF power levels are generally such that water cooling is essential.

• **Size constraints.** Good manufacturers are well aware of the need for compact solutions and offer a comprehensive range of devices of varying size. Dimensions will depend on the interaction material and cooling requirements. However, today, even high-power water-cooled devices can often be supplied in a package that is as small as a matchbox.

Electro-optic Q-switch

The application of an electric field to an electro-optic material can change its refractive index. The phenomenon is known as the Pockels effect and is often used to rotate the polarization of an incoming optical beam. By placing an electro-optic material between two crossed polarizers, it is possible to make a Q-switch. When a half wave-voltage is applied to the cell, the resulting linear polarization is rotated through

90° and transmitted through the crossed polarizer. With no voltage present, transmission of the light beam is blocked.

Pockels cells are frequently used in a double-pass configuration for laser Q-switching applications (figure 1) in order to decrease the required drive voltage. The latter depends on the material and varies with the optical wavelength.

The material potassium di-deuterium phosphate (KD*P) is widely used in electro-optic switches and modulators. Extinction ratios for these cells are typically greater than 2000:1 in the visible and near-infrared, and values of 5000:1 are often attained. Fast switching speeds, when risetimes are a few nanoseconds, require careful attention to the design of both the cell and the electrical driver. Rectangular-gated transmission periods as short as a few nanoseconds usually require the cell to be part of an electrical transmission line. For Q-switching with long gate times or a high-repetition rate, care must be taken to avoid acoustic ringing in the cell.

The latter occurs because materials with an electro-optic response also often have a piezoelectric response. The rapid switching of electric field can set up acoustic vibrations that alter the transmission of the Q-switch. These problems may be alleviated by cell design and careful choice of material. For example, the electro-optic material beta barium borate (BBO) has a small piezoelectric response relative to its electro-optic response and is a good choice for high-frequency response. BBO cells have been used for laser Q-switching at repetition rates in excess of 100 kHz. KD*P cells are typically used for Q-switching at rates of below 10 kHz.

BBO also offers advantages for high average-power applications. KD*P still retains an intrinsic absorption of approximately 0.002 cm^{-1} at 1064 nm. Average power limits are approximately 20 W for 1 cm diameter KD*P cells. Small beams of the order of 1 mm in diameter can have problems with thermal focusing. Single-shot laser-induced damage thresholds are roughly 15 J/cm^2 in 10 ns pulses and are usually limited by cell windows. It is advisable to stay below this value by about a factor of 10 for multiple-pulse applications. The BBO crystal alone has good average power capability. Water-cooled BBO cells have operated at 200 W average power.

Mechanical Q-switch

This is usually a spinning mirror. The cavity Q goes high (low loss) when the cavity mirrors are in alignment. The problems with this technique are that it requires physically large components and the switching speed is slow. However, it is useful at wavelengths where no other method is available. Mechanical Q-switches are rarely found today in industrial or medical applications.

Passive Q-switch

In passive Q-switching, a saturable absorber is used to introduce a variable loss in a laser cavity. As light builds up in the cavity, the absorber saturates and "bleaches", opening the cavity for a very short period of time. Contemporary methods use doped garnets. The benefits of saturable absorbers are that there is only one optical component and no electronics. The limitations are wavelength, synchronization and pulse energy variability.

About the author

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