LASER Q-SWITCHING	KỸ THUẬT TẠO LASER XUNG (KỸ THUẬT CHUYỂN LASER HOẠT ĐỘNG Ở CHẾ ĐỘ LIÊN TỤC SANG CHẾ ĐỘ Q-SWITCH, CÔNG TẮC Q HAY XUNG KHỔNG LỒ)
Q-switching is a widely used laser technique in which we allow a laser pumping process to build up a much larger than usual population inversion inside a laser cavity, while keeping the cavity itself from oscillating by removing the cavity feedback or greatly increasing the cavity losses—in effect by blocking or removing one of the end mirrors. Then, after a large inversion has been developed, we restore the cavity feedback, or “switch” the cavity Q back to its usual large value, using some suitably rapid modulation method. The result in general is a very short, intense burst of laser output which dumps all the accumulated population inversion in a single short laser pulse, typically only a few tens of nanoseconds long. There are many practical applications, including laser ranging, laser cutting and drilling, and nonlinear optical studies, where such a short but intense laser pulse is much more useful and effective than the same amount of laser energy distributed over a longer time. The Q-switching approach is therefore a technique of great practical importance in many different laser systems. In the present chapter we examine the general characteristics of laser Q-switching, and some of the lasers and modulation techniques that are useful for Q-switching; and then review some of the fundamental	Công tắc Q là một kỹ thuật laser được sử dụng rộng rãi giúp chúng ta có thể tạo quá trình đảo lộn mật độ cao hơn bình thường bên trong buồng cộng hưởng của một laser đang hoạt động (đang bơm), trong khi vẫn giữ nguyên chế độ dao động của buồng cộng hưởng thông qua việc loại bỏ phản hồi trong buồng cộng hưởng hoặc tăng tổn hao cộng hưởng – bằng cách khóa hoặc loại bỏ một trong các gương ở hai đầu buồng cộng hưởng. Sau khi quá trình đảo lộn mật độ đã lớn đáng kể, chúng ta phục hồi lại phản hồi buồng cộng hưởng, hoặc "chuyển" Q của buồng cộng hưởng trở lại giá trị lớn thông thường của nó, sử dụng một số phương pháp điều biến nhanh. Nói chung, kết quả tổng thể là một khối tín hiệu laser đầu ra gộp tất cả sự đảo lộn mật độ tích lũy thành một xung laser ngắn duy nhất, thường chỉ dài vài chục nano giây (hiện nay đã đạt đến femto giây). Trong nhiều ứng dụng thực tế, như xác định khoảng cách bằng laser, khoan và cắt bằng laser, một xung laser ngắn và mạnh sẽ có hiệu quả hơn nhiều so với các xung dài năng lượng thấp. Do đó, phương pháp công tắc Q có ý nghĩa quan trọng trong thực tế và được sử dụng trong nhiều hệ thống laser khác nhau. Trong chương này, chúng tôi trình bày những tính chất chung của quá trình Q-switch laser, và một số laser cùng với các kỹ thuật điều biến có thể áp dụng trong kỹ thuật cộng

analytical concepts that apply to laser Q-switching in actively, passively, and repetitively Q-switched lasers. 26.1 LASER Q-SWITCHING: GENERAL DESCRIPTION The fundamental dynamics of laser Q-switching, or giant pulsing, are shown, schematically in Figure 26:1. As illustrated there, we assume that the cavity loss in the laser cavity is initially set at some artifically high value—that is, at an artificially low value of the laser cavity Qc—while the inversion, and hence the gain and the stored energy, in the laser medium are pumped up to a value much larger than normally present in the oscillating laser. In essence, we block one of the laser mirrors to prevent the build-up of oscillation, while the laser pumping process builds up the population inversion over some period of time to a larger than normal value. The cavity loss is then suddenly lowered to a more normal value—in other 1004 words the cavity Qc is suddenly “switched” to a higher value—with the result Figure 26 2 »M some of the more common Q-switching methods that are employed in p^tical laser systems, UjM> «*■""« st<“^ ‘^triioSi teUt ^e most direct and one of the earliest i O end mirror of the laser on a rapidly?^ ?pf™tt2tof®rsoihaft'he SSTcan oscillate only during the brief inter¬val when the mirror rotates	tắc Q ; và sau đó nhắc lại một số khái niệm giải tích cơ bản của chế độ phát laser công tắc Q trong các laser công tắc Q chủ động, thụ động và lặp lại. [redacted] [redacted]

through an aligned wlth ,

°P7ht method, although cheap and simp^ has numerous practical disadvam taJs Len with the highest-speed motors (Waring Blendor motors were reputed to be extremely good!) this approach suffers from uncertain timing, slow switch-wLeedTck of reliability, and vibration and mechanical noise which lead to Snment difficulties in the direction perpendicular to the plane of rotation, lb avoid the latter, a rotating 90“ prism rather than a rotating mirror was oft emlTufmethod is now used if at all only on very long laser cavities at very long laser wavelengths—e.g., long C02 or far infrared molecular lasers alignment is less critical and other modulation techniques ay

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(2) Electrooptic Q-Switching: An electrooptic modulator, as we df^lbe^ in the PreviOUs_ni5ptET7TT5TisIsti-in general of an electrooptic crystal which be- ^ comes birefringeat under the influence of an applied electrical voltage, plus one ton jr. &!n«iHpl t.hp laser! cavitv.l In one form or more prisms or other polarizing elements inside the laser^vity-jln one of electrooptic Q-switch, an applied voltage sufficient to make the Pockels crys-tal into a quarter-wave plate is initially applied. Energy circulating once around the laser cavity then has its polarization rotated by 90° about the cavity axis, so that all the circulating energy is

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coupled out of the cavity by the polarizing element after just one round trip. Switching the cavity to a low-loss condition is then accomplished by suddenly turning this voltage off (referred to as “crowbarring” the voltage across the modulator). As an alternative, a fixed quarter-wave element can create the high- loss condition with no voltage applied, and the Pockels cell can then be switched on to cancel this birefringence; but this approach requires an additional element inside the laser cavity. Electrooptic Q-switching provides the fastest form of Q-switching (switch¬ing time < 10 ns), with precise timing, good stability and repeatability, and a large hold-off ratio (i.e., large insertion loss in the low-Q state). This approach requires, however, both a fairly expensive electrooptic crystal and a very fast-rising high-voltage pulse source (at least several kV in a few tens of nanoseconds). Nanosecond rise-time pulses at this voltage level are difficult to obtain, and can produce severe electrical interference in nearby electronic equipment. In addition, this approach needs several elements inside the laser cavity, and these elements (particularly the Pockels crystal) may be both optically lossy and subject to optical damage at the high intensities inside the Q-switched laser. (3) Acoustooptic Q-Switcliing: We also have described in the previous chapter the 'use of an acoustooptic modulator, in which the index grating pro-duced by an rf	[redacted] [redacted] [redacted]

acoustic wave Bragg-diffracts light out of the laser cavity. Acous-tooptic modulators have the advantages of very low optics' insertion loss, rel¬atively simoie rf drive circuitry, and ease of use for repetitive Q-switching at kHz repetition rates. They have only relatively slow opening times, however, as well as low hold-off ratios. Hence they are primarily employed for lower-gain cw- pumped or repetitively Q-switched lasers (as we will describe in more detail in a later section of this chapter). ^ Iv© r

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(4) P*miv* Saturable-Absorber Q-Switching: Passive Q switching (also described in more detail in a coming section) uses some form of easily saturable absorbing medium inside the laser cavity. Laser inversion is built up by the pumping process until the gain inside the cavity exceeds this absorption, and laser oscillation begins to develop inside the cavity. This oscillation at some rela-tively low level then rapidly saturates the absorber and thus opens up the cavity, leading to the development of a rapid and intense oscillation pulse. Saturable ab-sorption using an organic dye solution in an intracavity cell is the most common form of passive Q-switching, although there are other systems as well.

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Passive Q-switching is generally simple, convenient, and requires a minimum of optical elements inside the laser and no external driving circuitry. It is subject to some shot-to-shot amplitude fluctuations and timing jitter, however, and ex-ternal apparatus must be synchronized to

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the timing of the laser pulse rather than vice versa. In addition, the absorbing dyes may need careful initial adjustment and may be subject to chemical or photochemical degradation in use. Passive Q-switching is nonetheless quite widely used in practical Q-switched lasers.

(5) ThjpJilm Q&vitehing: A somewhat unusual form of saturable ab¬sorber Q-switching is the use of a thin absorbing or metallic layer on a glass or mylar substrate, with the laser energy focused to a small spot on this layer. When laser oscillation first begins to build up in this cavity, the thin absorbing coating very rapidly burns away and is vaporized as the laser oscillation builds up from noise. This makes a particularly simple and fast-opening Q-switch

FIGURE 26.1
Laser Q-switching, step-by-step.

that the round-trip gain after switching is much larger than the cavity loss. The initial spontaneous emission or noise level in the laser cavity then immediately begins to build up at an unusually rapid rate, soon developing into a rapidly rising and intense burst, or “giant pulse,” of laser oscillation. This oscillation burst rapidly becomes sufficiently powerful that it begins to saturate or deplete the inverted atomic population—in essence to “burn up” the inverted atoms in a very short time. The oscillation signal in fact rapidly drives the inversion down

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well below the new cavity loss level, after which the oscillation signal in the cavity dies out nearly as rapidly as it rose. The entire process is somewhat similar to an unusually rapid and intense "spike" of the type we described in the preceding chapter. The oscillation build-up interval, and particularly the output pulse duration, are generally much shorter than the pumping time during which the population inversion was created. The inversion built up during a long pumping time is thus dumped during a very short pulse duration. The peak power in the Q-switched giant pulse can be three to four orders of magnitude more intense than the cw long-pulse oscillation level that would be created in the same laser using the same pumping rate.	[redacted] Checked