ACTIVE Q SWITCHING TECHNIQUE FOR PRODUCING HIGH LASER POWER IN A SINGLE LONGITUDINAL MODE

Indexing terms: Q switching, Laser modes, Electro-optical effects, Solid lasers, Frequency stability

A Pockels-cell Q switch has been operated in a manner analogous to a saturable absorber, thus allowing the simple and reliable selection of a single longitudinal mode. A TEM_{00} mode Nd–$CaWO_4$ laser has produced 400 kW pulses in a single longitudinal mode with a shot-to-shot frequency stability of about $0{\cdot}01\ cm^{-1}$.

This letter reports the use of an electro-optic Q switch in a way which is analogous to a saturable absorber Q switch. The well known disadvantages of saturable absorbers are thereby avoided, while the desirable attribute of providing a long buildup time for the giant pulse is retained. This long buildup time has been shown[1] to be most important for mode selection, since very many passes through the mode-selecting element can then take place. In a previous publication,[2] we reported the use of a Pockels-cell Q switch which was opened in two stages as a means of producing a deliberately lengthened buildup time. Single-mode operation was thus obtained with a 2-plate resonant reflector as the frequency-selective element. With the technique reported here, a considerably longer buildup time is achieved and the increased mode selection which results from this has permitted the use of much simpler mode selectors, such as single-plate etalons used either in reflection or in transmission.

The laser used in our experiment* has given 400 kW of TEM_{00} mode power in a single longitudinal mode with a shot-to-shot frequency stability of the order of $0{\cdot}01\ cm^{-1}$. Similar performances can be expected from ruby and Nd–y.a.g. lasers. Other lasers, operating at wavelengths for which saturable absorbers are not suitable, can now be mode-selected in this simple and reliable way.

The experimental arrangement is shown in Fig. 1. The resonator is formed by a high-reflectivity dielectric-coated concave mirror (2 m radius of curvature) and a plane reflector at 75 cm separation. The TEM_{00} transverse mode is selected by means of a 1·4 mm-diameter aperture. Fig. 1 shows a tilted dielectric-coated etalon used as axial mode selector[3] and a dielectric-coated plane output mirror. The plane mirror was antireflection-coated on the back surface to avoid additional resonances leading to complex mode-selection behaviour. Good results have also been obtained when the plane mirror and tilted etalon were replaced by a 2-plate resonant reflector or by a single uncoated glass-plate reflector.[4] A calcite block polariser ensured that only the horizontal polarisation (i.e. ordinary polarisation in the calcite) could resonate, since the extraordinary polarisation suffered double-refraction walkoff which was sufficient to remove it from the resonator. The extraordinary beam was intercepted by a silicon photodetector which could thus monitor the laser power during the buildup phase.

The sequence of events leading to a single-mode giant pulse is as follows. The Pockels-cell voltage is adjusted so that the horizontally polarised light (i.e. perpendicular to the plane of the page in Fig. 1) incident on the cell from the right will be returned to the calcite with only a small component of horizontal polarisation. The remainder of the returning light, having a vertical polarisation, will walk off and then be monitored by the photodiode. This adjustment of the Pockels-cell voltage is analogous to the adjustment of absorber concentration when a saturable absorber Q switch is used. The flash lamp is now fired and the gain increases until, eventually, a net gain of greater than unity is reached for the horizontal polarisation. The laser power then begins to build up from noise, and the output from the monitor photodiode is used as a trigger to switch off the Pockels-cell voltage (i.e. open the cell), when a preset photodiode signal is reached. If the Pockels cell were not switched open, the laser output would consist of a train of relaxation-oscillation spikes. The preset trigger voltage is therefore chosen to correspond to a power level in the laser which is just less than the peak power which would be reached on the first of these spikes. This level is determined empirically.

* Modified Laser Associates Nd–$CaWO_4$ laser

During the slow buildup of this first spike, considerable mode selection takes place via any frequency-selective elements, and a single longitudinal mode can easily be selected. When the Pockels cell is switched open, the vertical polarisation sees a large gain, and the selected mode is then amplified to produce a giant-pulse output from the plane mirror. The photodiode is protected from the high power, since, when the Pockels-cell voltage is zero, there is no extraordinary-polarisation component present. The trigger voltage from the photodiode may be conveniently used to synchronise other equipment with the giant pulse. The technique thus gives a Q switching behaviour which is very closely analogous to that of a saturable absorber. In particular, the buildup time is comparable with that obtained with a saturable absorber.

A detailed discussion of the principles underlying the choice of mode-selecting device will be deferred to a fuller publication. The choice is limited essentially by the conflicting requirements that adjacent reflectivity maxima of the etalon must be sufficiently close to give good selection between adjacent modes, but sufficiently well spaced to ensure that only one maximum falls within the gain-narrowed output of the laser. Three different mode selectors have been used, and all have given reliable single-mode operation. These were

(*a*) a 2-plate resonant reflector

(*b*) a reflector consisting of a single etalon of uncoated glass

(*c*) an intracavity dielectric-coated etalon used in transmission.

It has even proved possible to obtain single-longitudinal-mode oscillation without any mode selectors at all in the cavity, a result that has previously been reported only for

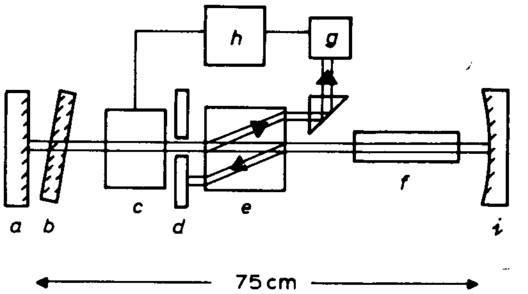

Fig. 1 *Laser-resonator arrangement*

a Plane reflector with antireflection-coated back surface
b Tilted-etalon mode selector
c Pockels cell
d Transverse mode-selection aperture
e Calcite-block polariser
f Nd–$CaWO_4$ laser rod
g Silicon photodiode
h Trigger electronics for Pockels cell
i High-reflectivity concave mirror

ruby lasers Q switched by saturable absorbers.[5, 6] This is not presently understood, since the gain-narrowing predicted by Sooy's analysis[1] is not sufficient to select a single mode in our laser. Despite this possibility of dispensing with mode selectors, it has been generally found worthwhile to add some mode selection for better stability and reliability.

The spectral output of the laser was monitored by frequency-doubling the 1·06 μm output in a KDP crystal and then the 0·53 μm light was sent into a defocused confocal Fabry-Perot interferometer.[2, 7] This instrument has a free spectral range of $0{\cdot}1\ cm^{-1}$ and a finesse of more than 20, and allows adjacent longitudinal modes to be resolved since the mode separation is $0{\cdot}007\ cm^{-1}$. Visual observation of the Fabry-Perot fringes while the laser was operating at 10 pulse/s made it particularly simple to angle-tune the transmission etalon to obtain single-longitudinal-mode operation. Single-mode operation has been maintained with excellent reliability with a TEM_{00} output of 400 kW at 10 pulse/s and with a shot-to-shot frequency stability of the order of $0{\cdot}01\ cm^{-1}$.

In conclusion, an active Q switch has been demonstrated which allows single-longitudinal-mode selection in high-power lasers. This Q switch avoids the problems of saturable absorber Q switches, the most serious of which, for neodymium lasers, has been the chemical instability of the solutions. Other laser transitions (e.g. Nd–y.a.g. 1·32 μm, Ho–y.a.g. 2·1 μm), for which saturable absorbers are not available, can also be mode-selected by this technique. The good shot-to-shot frequency stability, and the high spectral brightness that this technique offers, will be useful for applications in such areas as multiple-exposure holography and, in nonlinear optics, as a pump for parametric oscillators.

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