Quantum Electronics and Electro-Optics
Edited by P. L. Knight

HIGH POWER, SINGLE FREQUENCY OPERATION OF A Q-SWITCHED TEM$_{00}$ MODE Nd:YAG LASER

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Many of the applications of solid state lasers, and NdYAG in particular, stem from their ability to produce a very intense Q-switched output (pulse energies up to hundreds of mJ and pulse durations $\sim 10^{-8}$s). Users of these lasers are becoming increasingly aware of the value, or indeed the necessity for some applications, of a laser output which is very 'clean' and repeatable. Hence there is a demand, not only for high power, but for the laser output to be diffraction-limited and in a single longitudinal mode (SLM). Techniques for achieving reliable single mode operation in stable resonators are well known, involving the use of apertures and etalons. However it is commonly found that if this mode selection is to function reliably the available multimode output may be reduced by something like an order of magnitude, down to perhaps 10-20mJ. Using a NdYAG laser in an unstable resonator configuration, output energies of $\sim$200mJ have been achieved (Herbst et al 1977), but the nonuniform intensity distribution of the diffraction-coupled output beam is an inconvenience in many situations (Hanna and Laycock, 1979) and the resonator does not lend itself readily to longitudinal mode selection (Hanna and Laycock, 1979; Park and Byer, 1981). Justification for the use of unstable resonator configurations has sometimes been made by implying that stable resonators have an inevitable shortcoming, namely that operation with a large area TEM$_{00}$ mode is highly unreliable since the spot size is then a very sensitive function of the resonator parameters. Thus if a large spot size is achieved by arranging the resonator to be nearly plane/plane (e.g. by simply adding a lens to compensate the thermal lensing in the laser rod), then unreliable operation is certainly the result. However, stable resonators can be designed which avoid this problem - they have been referred to as 'dynamic stable resonators' (Steffen et al., 1972; Lortscher et al, 1975). Such a resonator design, based on a telescopic resonator (Sarkies 1979) has allowed us to achieve reliable operation of a pulsed NdYAG laser with a TEM$_{00}$ mode of 5mm diameter (2W) (Hanna et al 1981a, 1981b). In addition we have Q-switched this laser using a technique which we refer to here as 'prelase-Q-switching' (when first developed this technique was called 'slow-Q-switching' (Hanna et al 1972a, 1972b) and this has led to SLM operation with extremely clean pulses, free from any discernible mode-beating at the 100mJ level (Berry et al 1981).

The principle behind the 'dynamic stable resonator' is the choice of resonator parameters such that the spot size, w, within the laser rod is insensitive to fluctuations of the resonator parameters, such as the focal length of the thermally-induced lensing in the laser rod. This can be effected by the half-confocal resonator (Fig. 1) in which the laser rod and compensating lens (both assumed close to the left hand mirror), have a combined focal length f, related to the resonator length L, by f=2L.

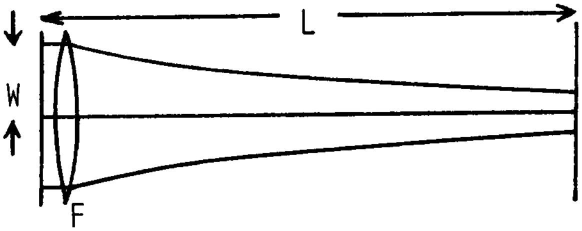

Fig. 1 Plano-concave resonator.

It is readily shown that dw/df is then zero, where w is the spot size at the left hand mirror (and hence in the laser rod). This spot size is therefore stable with respect to fluctuations of the rod focal length. Furthermore the confocal arrangement offers the best selectivity for the TEM_{00} mode (Li 1965), so reliable TEM_{00} operation can be achieved with this half-confocal geometry. The spot size w is given by the relation, $w=(2L\lambda/\pi)^{\frac{1}{2}}$, and from this it is seen that a spot size of 2.5mm (λ=1.06µm) would imply an inconvenient resonator length (9m).

The resonator length can be reduced by introducing a telescope as in fig. 2. The telescope achieves two things: firstly it provides a conveniently adjustable lens with which to compensate the rod lensing - with the telescope appropriately adjusted the resonator is again equivalent to a half confocal resonator, thus providing the desired stability and mode-selectivity; secondly, with this confocal adjustment the spot size is given by $w=M(2L\lambda/\pi)^{\frac{1}{2}}$, thus showing that the same spot size in the laser rod can be achieved with a resonator length M^2 shorter, where M is the telescope magnification. (The above expression for w assumes that the rod and telescope are close to the left hand mirror, but this condition can be relaxed without sacrificing the analytical simplicity (Hanna et al, 1981b)).The disadvantage of the telescopic resonator is that the spot size on the right hand mirror is now M times smaller, hence the Q-switched output energy is limited by damage to this mirror.

Fig. 2 shows one resonator configuration that we have used. The right hand mirror, which serves as output coupler, is a glass plate resonant reflector, uncoated to alleviate damage. The negative lens of the telescope is also uncoated for the same reason. Other components are in the expanded beam. Up to 400mJ of TEM_{00} output has been extracted in fixed Q operation. When Q-switched the resonant reflector suffers damage at 170mJ output, but trouble-free output at the 100mJ level has been maintained for over a year, with excellent reliability, in a very clean TEM_{00} beam, free from rings or other visible blemishes. With some modifications to this resonator we envisage the possibility of obtaining Q-switched TEM_{00} outputs of up to $\sim$300mJ.

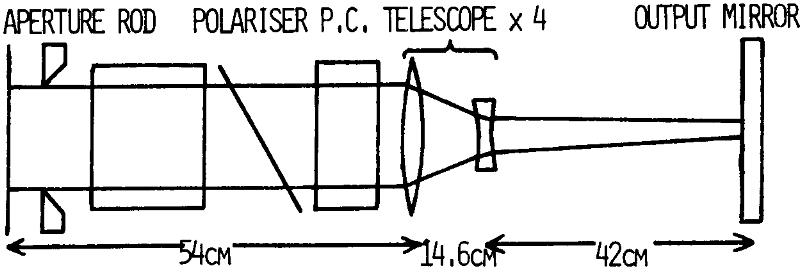

Fig. 2 Telescopic resonator; dimensions are indicated. The spot size, w, in the laser rod is 2.3mm and aperture diameter 7mm.

SLM operation is achieved in the resonator of fig. 2 by operating the Pockels cell (P.C.) in a manner analgous to a saturable absorber. Thus the P.C. voltage is first held somewhat below the $\lambda/4$ voltage (i.e. the P.C./polariser has a finite transmission) so that lasing will begin near the end of the pump pulse. This initial laser oscillation ('prelase')grows from the noise level rather slowly since the net gain is only small. Typically around 1000 resonator round trips will elapse before the prelase intensity reaches a level of $\sim$1W. During this time a considerable degree of mode selection can be achieved, much more than from a conventionally Q-switched laser where the resonator is suddenly presented with a very large net gain and growth from noise to peak output takes place in a few tens of round trips. The 'prelase' signal is detected (usually we monitor the light rejected by the polariser) and on reaching the level of$\sim$1watt the detector signal is used, via trigger electronics, to switch the P.C. fully open. The single mode radiation is thus amplified to the full Q-switched power. In practice we have found that an adequate degree of selection between adjacent modes can be provided by a thick (7.5cm) resonant reflector (RR) as the right hand mirror in fig.2. In addition an uncoated glass plate ($\sim$6mm),used as a tilted transmission etalon, suppresses oscillation on all but one resonance of the RR. Viewed with a fast detector (response $\sim$0.5ns), clean pulses free from any discernible mode-beating are obtained at $\sim$100mJ pulse energy. The pulse amplitude stability is enhanced by this Q-switching technique since the P.C. is always opened when the same gain (and hence stored energy) is reached. Since a $\sim$1% depth of modulation due to mode-beating would be readily observable, we can deduce that the intensity in modes adjacent to the dominant mode is a factor of $\sim 10^5$ smaller. Typically we find that these beat-free pulses can be maintained (at $\sim$10Hz)for around 1 minute before drifting into two-mode operation, characterised by a deeply modulated pulse. A drift of optical length of the resonator by $\lambda/4$ will produce this effect. Single mode operation is readily restored by a further change of $\lambda/4$ and this is conveniently achieved by transverse displacement of an intracavity wedged plate. This technique should lend itself to a particularly simple feedback scheme by which beat free (i.e. less 1% modulation, say) pulses should be maintained indefinitely.

In conclusion we have obtained extremely clean (both spatially and temporally) pulses of ∿100mJ from a Q-switched NdYAG laser, by selecting a TEM_{oo} mode and a single longitudinal mode. Considerable further progress, towards energies of ∿300mJ, appears feasible.

This work has been supported in part by the SERC and J.K. Lasers. One of us (AJB) holds a Case Studentship sponsored by J.K. Lasers.

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