Coupled Cavities Scheme: An Efficient Method for Pumping Low Absorption Laser Media in C.W. Q - Switched Operation

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Recently a family of transition metal ions doped crystals have demonstrated C.W. laser action in the near infrared[1]. They essencially compete in the near infrared with color centers[2], with the advantage of beeing stable but with different spectroscopic properties, i.e. low transition cross sections and long decay times[3]. These properties lead to small efficiences when these lasers are collinearly pumped by other lasers. This can be partially overcome by multiple passages throught the laser medium, increasing the net absorption[4]. An ideal alternative for pumping efficiently these laser media is intracavity pumping, but this is not feasible in C.W. operation due to the limited gain of the pumping laser.

In order to increase the pumping efficiency we envised a coupling cavity scheme in wich the pump beam is exactly mode matched to the pumped laser cavity in such way that the non absorbed light is reinjected into the pump laser; therefore the effective loss for the pumping laser is the absorption of the pumped laser medium. This coupling scheme is shown in figure 1. The pump laser (Nd:YAG) consists of mirrors M_1 and M_2 and the pumped laser cavity is a cryogenic astigmatically compensated cavity[5] formed by mirrors M_4, M_3 and M_0. Mirrors M_3 and M_4 are gold coated, therefore high reflectors for the pump light and for 1.5 μm of the used laser medium ($KCl:Tl^0(1)$ color centers). These centers show a spontaneous decay time of 1.6 μs[6]. Prism P_1 is used to split the beams (dispersion is 1 *cm/m for these wavelenghts)* and allows for collinearity of these beams in the pumped gain medium region. Prism P_2 extracts the 1.5 μm beam. Both prisms are Brewster prisms (dense flint). The output coupler is 10% at 1.5 μm with a curvature radius of 3 m.

In these coupled cavities scheme, the reinjected beam interferes with the main cavity one, reinforcing the perfect matched modes. As the gain bandwidth is 1000 times the main cavity mode spacing, there will be always several modes that will oscillate simultaneously, depopulating efficiently the main laser gain medium. For the matched modes the effective reflectivity is dependent on the transmition of the pumped laser medium and is given by $R_{ef} = \{(\sqrt{R} + \tau)/(1+\tau\sqrt{R})\}^2$ R beeing the M_2 reflectivity at 1064 nm. To test the coupling of the cavities we firstly used a dummy crystal in place of the laser medium, obtaining the minimum laser threshold. In our case the laser could operate at the pump lamp current threshold. The KCl $Tl^0(1)$ crystal showed a 10% transmition at the pump wavelenght (non saturated). The output power as function of the arc lamp pump current is shown in fig. 2. The pump laser was chopped with a low duty cicle to avoid thermal problems in the crystal. At 29 Amps the Nd:YAG output power (free running) was 3.3 W, so the nominal efficiency is 40% for the extracted power. The laser operated in the Q-switched regime,and at the maximum output power the pulse frequency was 50 Khz, with a pulse duration of 1 μs (as shown in the insert of fig.2) for the pump laser. The frequency increases with the pump power.

The Q-switched operation can be understood considering that in this scheme the pumped laser medium also behaves as a saturable absorber having its transmition modulated by the incident intensity.At the begining of the operation the threshold is lowered to $g = g_t - [(1-R)\tau]\,(\sqrt{R} + \tau)$. At the growth of the field, the crystal transmition approaches unity, beeing determined by the residual losses of the coupled resonator, behaving essencially as 0% output coupling. The radiation field remains in the resonator decaing only due to the recovery of the pumped laser medium to the ground (absorbing) state. Therefore the unique source of loss for the pump laser is the absorption of the pumped laser medium, explaining the high pumping efficiency measured. The pulse duration is due to two factors; the maximum gain at the begining of the pulse with respect to the coupled cavity gain (~ 12%) and the rate of energy transfer from the main cavity to the coupled cavity times the decay rate of the pumped gain medium. The rate of decay depends on the fluorescence decay time and the stimulated decay due to its laser operation. The avarage decay rate of the color center, for the maximum pump power reduces the decay time by a factor of 20, so for an output coupling of 12% this leads to an effective decay time of 0.8 μs, very close to the measured one.

This methode can readily be used in other laser media by appropriated choice of optics and judicious choice of the coupling mirror and the q value of the slave resonator. A priori one can say that longer pulses can be expected.

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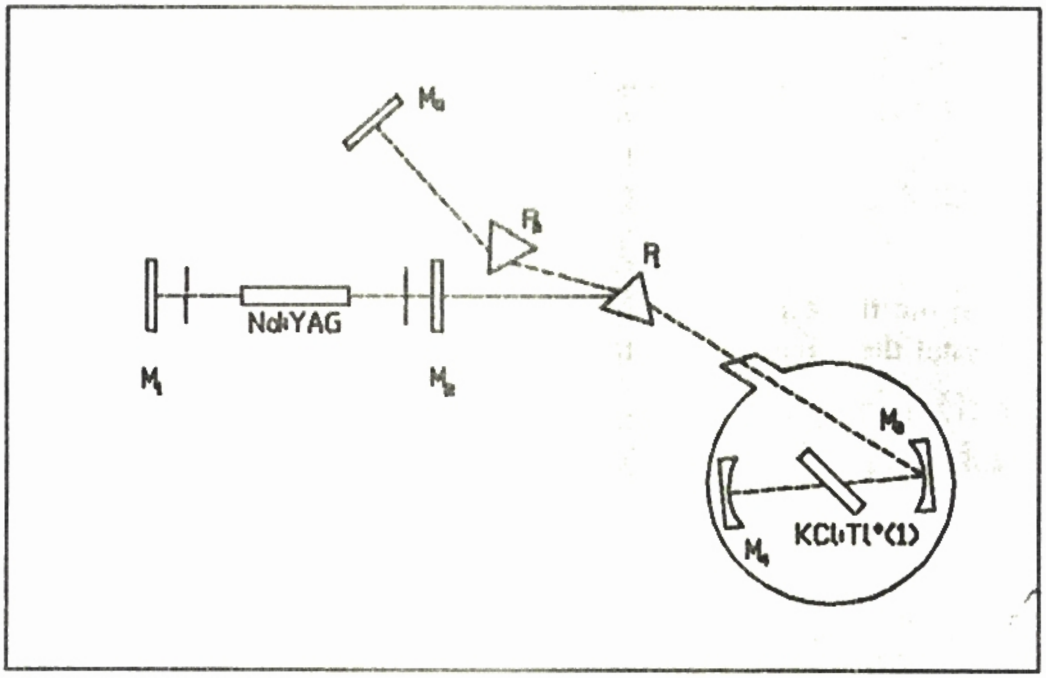

Fig. 1: Coupled Cavities Scheme

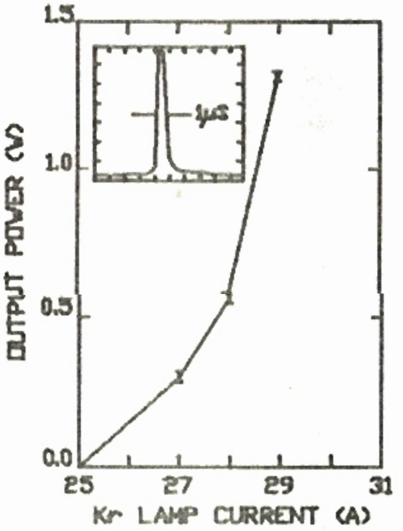

Fig. 2: C.L.L. Output Power
(Insert Pulse Duration)

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