EFFICIENT FREQUENCY DOUBLING OF SELF STARTING ADDITIVE PULSE MODE-LOCKED DIODE PUMPED Nd:YAG AND Nd:YLF LASERS

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Summary

Self starting additive pulse mode-locking was first achieved in Ti:Al_2O_3 [1], and was a significant development in the production of ultra short pulses. The technique utilises the phase dependent reflectivity from a resonant coupled cavity being intensity dependent due to the nonlinear element present. An initial intensity perturbation resulting from mode beating in the main laser is, in the presence of sufficient nonlinear feedback, progressively shortened and preferentially amplified on successive round trips, and grows to saturate the gain, resulting in steady state mode-locking [2,3]. By removing the need for active mode-locking, with its associated synchronisation problems, ultra short pulse durations were readily achieved, combined with a general simplification of the overall system. The wide applicability of the scheme has been demonstrated by its extension to other solid state gain media such as Nd:YAG [4], Nd:YLF [5] and Nd:Glass [6].

In this work, the Nd:YLF rod was oriented for operation at 1047nm. With a 17% transmission output coupler, the diode pumped Nd:YAG laser yielded a maximum output power of 250mW for 900mW of diode pump incident on the Nd:YAG rod. The Nd:YLF laser gave similar performance.

The nonlinear external cavity was formed by a beamsplitter of either 65% or 83% reflectivity and a 1m length of single mode non polarization preserving fibre. Efficient coupling into the fibre (>75%) was achieved using a 0.25P GRIN lens which was AR coated on the front face and coupled to the fibre with index matching fluid on the other, to eliminate spurious reflections. A similar arrangement was used to retroreflect back through the fibre. The retroreflecting mirror was mounted on a piezo-ceramic (PZT) for fine control and stabilisation of the external cavity length.

With an 83% reflectivity beamsplitter, mode-locking threshold in Nd:YAG corresponded to 40mW average power coupled into the fibre. The pulses had a FWHM of 1.7ps assuming a $sech^2$ pulse shape, up to an average output power of 45mW through the beamsplitter. Pumping beyond this level caused the pulse duration to increase, due to excessive self phase modulation in the fibre. Changing to a 65% reflectivity beamsplitter, the mode-locking threshold increased to 100mW coupled into the fibre, at which point the average output power was 70mW through the beamsplitter. The pulse duration was 2.0ps FWHM at the maximum available pump power, with an average output power of 110mW.

Using a 65% reflectivity beamsplitter, diode pumped Nd:YLF has given a 1.4ps pulse duration at 110mW average output power for 900mW of pump power. Mode-locking threshold corresponded to about 40mW average power coupled into the fibre. The Nd:YLF laser was noticeably more stable than the Nd:YAG system, even when operating close to threshold where the Nd:YAG laser would frequently jump out of lock.

Despite the modest output powers available from diode pumped lasers, their excellent stability can be exploited to give efficient second harmonic generation (SHG) by using external resonant enhancement cavities. Here, the laser output is efficiently resonated to a high circulating power in a low loss, matched cavity which contains the SHG element at an

intra-cavity focus. This has been demonstrated for cw [7] and mode-locked [8] lasers. Here, the enhancement cavity was a planar bow-tie ring configuration. All mirrors were highly reflecting at 1064nm at normal incidence, except for a 20% transmitting input coupler. The rear curved mirror was also highly transmitting at 532nm. The rear plane mirror was mounted on a PZT for cavity length stabilisation. For frequency doubling of the Nd:YAG laser, a 3mm long x-grown $MgO:LiNbO_3$ crystal was placed at the tighter intra-cavity focus where the mode radius ($1/e^2$) was about $40\mu m$. This was anti-reflection coated at both 1064nm and 532nm. The crystal was mounted in an oven for temperature tuned 90° phase-matching. With 110mW of time averaged power incident onto the enhancement cavity input coupler in 2.0ps pulses, 63mW of time averaged power at 532nm was obtained through the rear curved mirror. This represents an overall conversion efficiency of 56% of the Nd:YAG output into available 532nm output. The pulse duration was 2.0ps, assuming a $sech^2$ pulse shape. The output was in a clean TEM_{00} spot. With the laser cleanly mode-locked, the amplitude fluctuation in the second harmonic output of the enhancement cavity was no more than 1%.

The pulse durations achieved with Nd:YAG are close to the limit that can be supported by the linewidth. The linewidth of Nd:YLF is ~360GHz, and so could support pulse durations of ≤900fs. Other cavity configurations are being assessed [10] in the pursuit of shorter pulse durations. Scaling of the pump power to 6W by polarization coupling two 3W diodes is also being undertaken.

The high dispersion of $LiNbO_3$ is clearly limiting the expected pulse shortening in converting to the second harmonic. The use of the new nonlinear crystal, lithium triborate (LBO) in the enhancement cavity for doubling of the Nd:YLF laser should result in pulse shortening and a higher conversion efficiency at increased powers.

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