Pump Induced Loss in Directly Diode Laser Pumped Ti:Sapphire Lasers

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Abstract: Pump wavelengths of less than 460nm compromise the performance of Ti:sapphire lasers by inducing loss. This – and not pump brightness or absorption – is the primary performance limitation for diode-laser pumped Ti:sapphire lasers.

Introduction: Importance of Ti:Sapphire

- Ti:sapphire [1] is the most widely used gain material in scientific lasers, unrivalled in terms of tuning (100s of nm) and ultra-short pulse generation (<10fs possible).
- Widely used in e.g. precision spectroscopy, ultrafast science and biological imaging.
- Costly and bulky blue-green pump lasers are typically required:
  - Threshold typically large (~1W) – $\sigma\tau$ product is small; intrinsic losses are large.
  - Small pump absorption coefficient puts a premium of pump brightness.
- Compact, low cost pumps would improve applicability to applications beyond the lab.

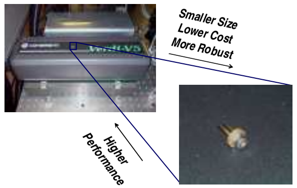

Fig.1: Comparison of a diode laser and a standard pump laser

CW and fs Diode-Pumped Ti:Sapphire Lasers

- Direct diode-laser pumping possible despite the wavelength mismatch (450nm; absorption peak 490nm) and reduced pump brightness (1W, M²~1.5x6).
- CW: 19mW output power for 1W diode-laser pump (fig. 2-4) [2].
- Modelocked: 9mW, 116fs transform-limited pulses for 1W diode-laser pump [3].
- A slow degradation of performance (minutes) until a steady-state is reached – the performance noted above is for the lower power steady state.

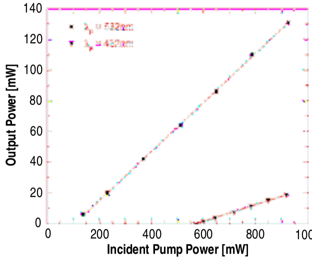

Fig.2: Comparison of performance for diode-laser (452nm) and conventional 532nm pumping

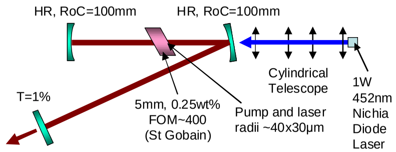

Fig.3: Schematic of diode-laser pumped Ti:sapphire laser

Fig.4: Diode-laser pumped Ti:sapphire laser

Pump Induced Loss: Effect on Laser Performance

- Lower performance than expected even accounting for reduced pump source brightness and wavelength mismatch (c.f. modelling based on [4]).
- Over a few minutes of diode-laser pumping CW output power reduces from 60mW to a steady state level of 19mW (not observed for 532nm pumping).
- Performance stable at this level (19mW) even after being switched off overnight.
- Initial performance recovered by pumping at 532nm for some tens of minutes.
- The nature of this degradation explored in a co-pumping experiment (figs.5, 6):
  - Pumping at 476.5nm and 532nm – no degradation in output power (fig.6)
  - Pumping at 457.9nm and 532nm – expected increase in power when 457.9nm switched on but slow degradation to steady-state; expected decrease and then slow increase back to original level when 457.9nm light blocked again. (fig.6)
- No reduction in fluorescence observed – indicative of an increase in loss rather than a reduction in gain.

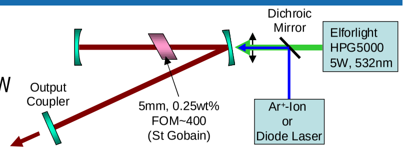

Fig.5: Schematic of the co-pumping experiment

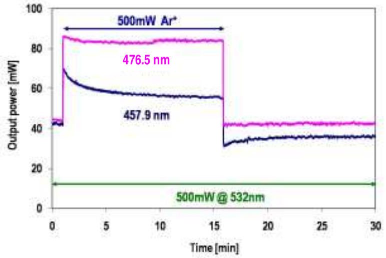

Fig. 6: Output power as a function of time for co-pumping as per fig.5

References:
1. Moulton, JOSA B, **3**, 125, 1986
2. Roth, OL, **34**, 3334, 2009
3. Roth, submitted to CLEO 2010.
4. Alfrey, JQE, **25**, 760, 1989
5. Payne, JQE, **24**, 2243, 1988
6. Hoffstädt, JQE, **33**, 1850, 1997

Pump Induced Loss: Wavelength Dependence

- Pumping on the available Ar⁺ lines, a clear reduction in performance can be seen for 457.9nm compared to the other lines (fig. 7)
  - This is also evident in the reduction in slope efficiency and increase in threshold (fig.8) – a clear difference between pumping at 457.9nm and 476.5nm and above.
  - This is reflected in the intracavity losses (fig.9): for a pump wavelength of 457.9nm, the loss is ~1% higher than at 488nm or 532nm. (Discrepancy between Findlay-Clay and Caird approaches is commonly observed for vibronic lasers e.g. [5].)
- Similar effects reported by Hoffstädt [6] in flashlamp pumped Ti:sapphire lasers and tentatively ascribed to charge transfer interactions between Ti^{3+}-Ti^{4+} pairs.
  - A fit to the absorption profile of Ti:sapphire based on the Jahn-Teller splitting of the upper level of Ti^{3+} (fig.10) suggests that the low wavelength tail (460nm and below) of the absorption can not be explained by Ti^{3+} alone.
  - It may be that a different centre or species is responsible for the induced loss. This is under investigation.

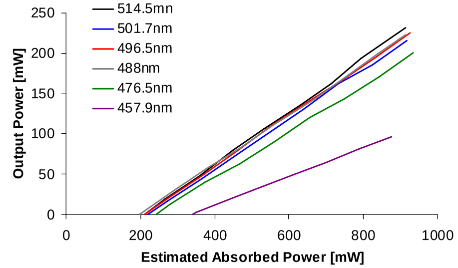

Fig. 7: Output power as a function of absorbed pump power for pumping with a variety of Argon-ion lines

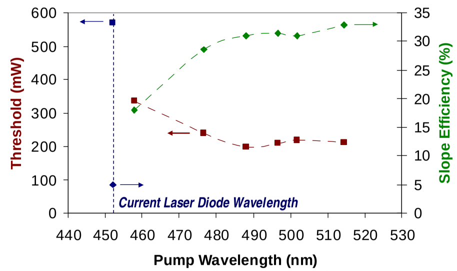

Fig. 8: Threshold and slope efficiency as a function of pump wavelength under Ar⁺ pumping. Blue points show diode-laser pumping data

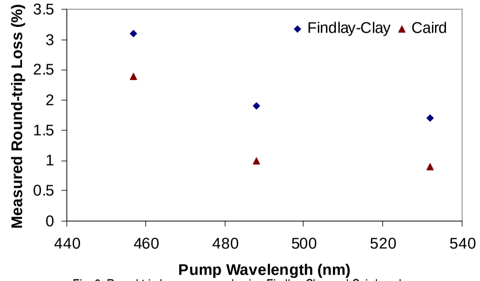

Fig. 9: Round trip loss, measured using Findlay-Clay and Caird analyses, as a function of pump wavelength (458, 488nm – Ar⁺; 532nm – doubled Nd:YVO$_4$)

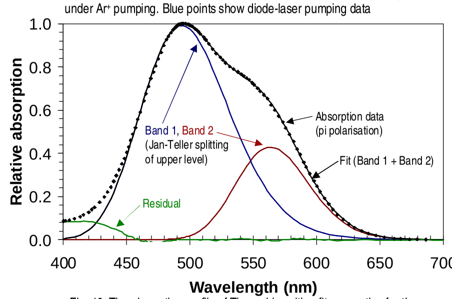

Fig. 10: The absorption profile of Ti:sapphire with a fit accounting for the Jahn-Teller splitting of the upper level

Conclusions:

- **19mW CW and 9mW in 116fs pulses demonstrated for 1W of diode-laser pump**
- **Shorter pump wavelengths (<458-477nm) induce additional loss, restricting performance**
- **Even so, CW output powers of ~100mW should be possible with double sided pumping**
- **The origin of the induced loss is not fully understood but appears to relate to absorption in a centre other than solely Ti^{3+}**
- **Progress of GaN diode lasers to longer wavelengths may soon circumvent this problem**

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