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Wavelength and polarisation dependence of dynamic pump-induced loss in Titanium:sapphire

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Abstract: We use the wavelength and polarisation-dependent power response of Ti:Sapphire resonators to demonstrate that the phenomenon of pump-induced loss in Ti:Sapphire is the product of two separate electronic excitations that interact.

1. Introduction

Performance improvements in diode-pumped Ti:Sapphire (dpTiS) lasers make these systems increasingly viable for applications where their conventionally pumped counterparts are too bulky or too expensive[1,2]. Advances in laser diode manufacturing have largely driven this progress, with 5W blue (445-465nm) diodes now widely available, as well as 1-2W diode in the 485-520nm region. Longer-wavelength, lower-power diodes are usually favoured in dpTiS, due to two additional considerations when pumping at blue wavelengths: (i) pump fraction[3], the absorption of pump light by the non-radiative 400nm residual band that underlies the pump band, and, the focus of this work (ii) pump-induced loss (PIL)[4]. Pump-induced loss was observed in the first dpTiS, and was characterised by a degradation of resonator power with time for blue (445nm) pumping. After a period of minutes, the laser reached a lower steady-state output power, but could be “annealed” back to the original higher power state by 532nm pumping over several hours. Though subsequent studies[5] have discussed this phenomenon, the origin and mechanism of the induced loss are not agreed upon[6].Here we use range of laser diode wavelengths in conjunction with polarisation control to add crucial detail to the understanding of PIL.

2. Experimental setup

Experiments were performed by logging the 800nm power output of a 3-mirror dpTiS resonator. Dichroic mirrors allowed pumping with 2 laser diodes, spatially-overlapped in the crystal. Half waveplates were employed for polarisation control of the wavelengths used; 405nm, 450nm, 490nm and 520nm. Though a co-pumping scheme was used, the pumps were used sequentially to (a) induce loss (various wavelengths), then (b) anneal the crystal (at 520nm). Each measurement thus had 2 phases: (a) loss, where the 800nm power begins at maximum and degrades to a low steady-state power and (b) annealing, where the 800nm power begins at a reduced level (P_L) from the previous loss phase, but increases over time to a higher steady-state power.

3. Results and discussion

We include result from two crystals here: (i) a 5.2mm St Gobain sample, $\alpha = 5.3cm^{-1}$ @ 515nm, and (ii) a 10mm Crystal Systems sample, $\alpha = 2.1cm^{-1}$ @ 515nm. Figure (1a) shows a plot of normalised power output for both crystals under π-pol 450nm pumping. The power level of crystal (i) decays to ~20% of its initial value within 30 minutes, while crystal (ii) exhibits steady output power. PIL is exemplified by crystal (i), while crystal (ii) shows no time-varying loss.

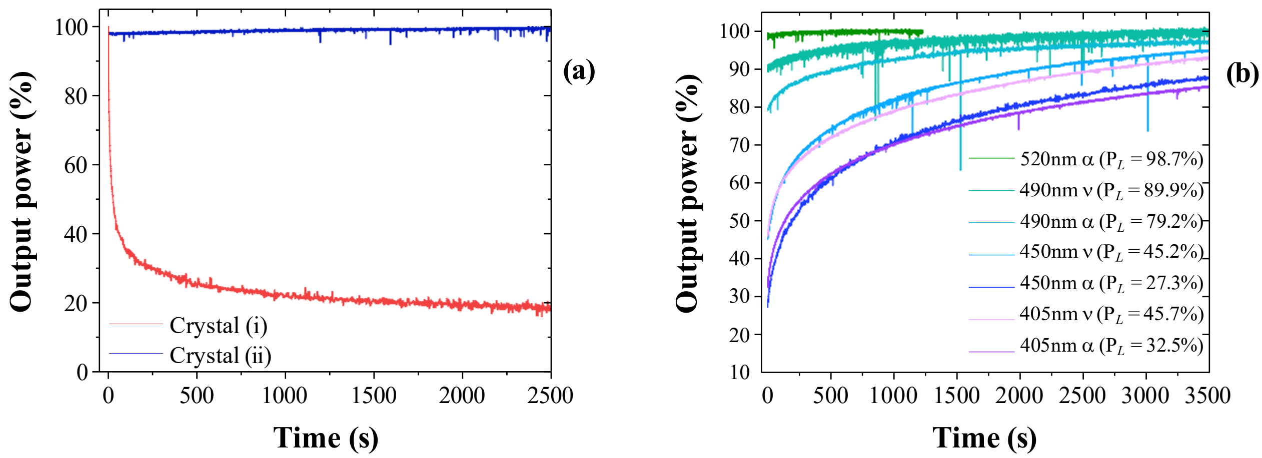

Figure (1): (a) Normalised resonator output power traces under π-polarised 450nm pumping for crystals (i) and (ii), and (b) resonator output during π-polarised 520nm annealing from the P_L state, annotated with the wavelength and polarisation of loss-induction preceding the annealing, and the starting power as a percentage of the final power.

We then examined crystal (i) under a range of pump wavelengths and polarisations. Quantification of PIL is obtained by referencing P_L to the final steady-state power obtained from the fully-annealed crystal. P_L can then be expressed as a percentage of the steady-state power, from which we infer the degree of PIL. Figure (1b) shows various annealing traces when pumping with π-pol 520nm for 1 hour. Each trace is annotated with the wavelength and polarisation of the preceding phase of loss-induction, and the relative P_L for each trace.
The degree of PIL varies by wavelength, with the most substantial loss induced by the σ-polarised 450nm pump. In all cases, σ-polarisation induces greater loss than π-polarised light of the same wavelength. Indeed, it is

possible to induce a small amount of loss using a 520nm pump, by rotating to the σ -polarisation. This exemplifies that both loss and annealing can occur at the same wavelength by adjusting only pump polarisation. Further, we find that the wavelengths that yield higher P_L, i.e. that induce less PIL, can be used to anneal Ti:Sapphire when loss has previously been induced using lower P_L wavelengths, indicating the significance of the initial state of the crystal in the loss/annealing mechanism. In these cases, the degree of annealing is still limited to the P_L of the annealing wavelength used. This suggests that pump wavelength establishes both the forwards and backwards rate of a dynamic process that governs PIL, and so determines an equilibrium level between the loss and annealed states.

A key result comes from irradiation of the Ti:Sapphire at 405nm. This wavelength has negligible absorption by the Ti^{3+} pump band, though is absorbed by the parasitic 400nm residual band with an absorption strength that increases with $[Ti^{3+}]^2$. Therefore, the 405nm can only be used to irradiate the crystal without the resonator reaching laser threshold. Though laser oscillation was not found to be prerequisite to loss or annealing for any other wavelength, irradiation by 405nm light alone had no effect on P_L in the subsequent 520nm annealing phase. We were able to induce significant loss, however, when pumping Ti:Sapphire with both 520nm and 405nm simultaneously (light and dark purple traces in Figure (1b)). As neither wavelength is individually capable of inducing loss, we infer that simultaneous absorption by both the Ti^{3+} pump band and a component of the 400nm residual band are required for PIL to occur.

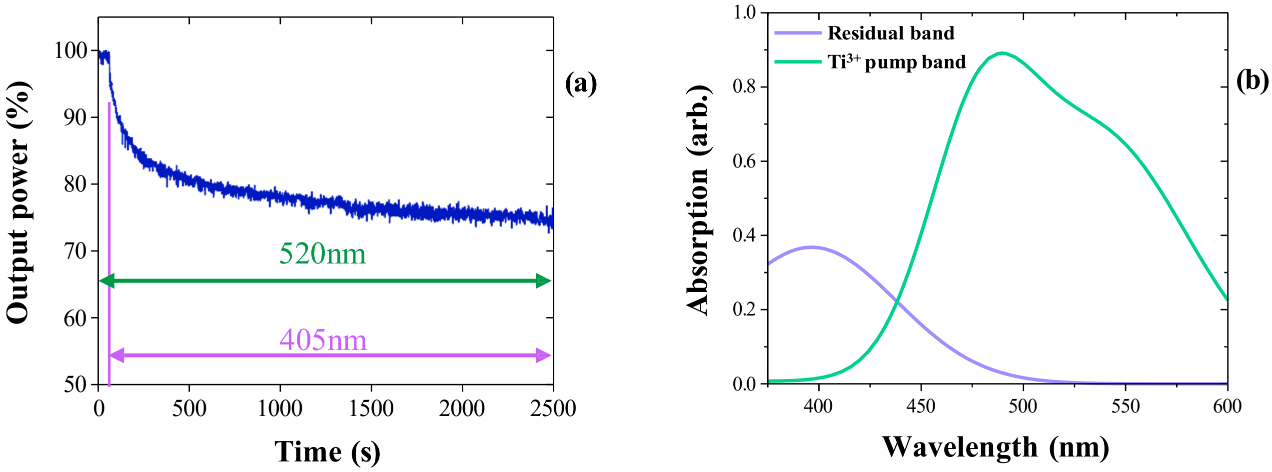

Figure (2): (a) Normalised output power for crystal (ii) under π-polarised 520nm pumping at the point when co-pumping with σ-polarised 405nm diode is initiated, (b) schematic absorption spectrum of Ti:sapphire in π-pol, delineating the residual and pump band contributions, noting the region of overlap between 400-500nm.

To support this, we applied the same 520nm and 405nm co-pumping arrangement to crystal (ii), which formerly did not exhibit PIL with 450nm pumping. Figure (2a) shows the normalised output power for the resonator as it deteriorates rapidly upon addition of the 405nm beam, demonstrating PIL. Finally, we observed that crystal (i) in a loss-saturated state with low P_L (<45%) can be slowly annealed through irradiation with 405nm alone. We quantified this by measuring a series of P_L values as a function of 405nm irradiation time, obtained by briefly allowing lasing with a 520nm pump.

4. Conclusion

Our results demonstrate that PIL involves both the residual absorption band and Ti^{3+} pump band. When excitation of these bands occurs together, which is possible across a sample-dependent range of blue-green pump wavelengths (Figure (2b)), it results in a photoproduct that increases crystal loss. Individually, however, each excitation can result in dissociation of the photoproduct, i.e. annealing. We propose that the degree of loss is linked to the relative intensities of the residual band to the pump band at the wavelength of the pump, and that σ-pol give rise to a larger ratio, as supported by spectroscopic data[6], and thus greater PIL. Greater PIL, over a wider wavelength range, is expected in more highly-doped samples owing to the $[Ti^{3+}]^2$ dependence of residual band absorption strength. Taken with pump fraction, which now seems closely-linked with PIL, our results suggest that shorter pump wavelengths are best used in conjunction with low-doping Ti:Sapph crystals.

5. References

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