GENERATING PICOSECOND PULSES FROM Q-SWITCHED MICROCHIP LASERS

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Except where acknowledged in the customary manner, the material presented in this thesis is, to the best of my knowledge, original and has not been submitted in whole or in part for a degree in any university.

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Abstract

Since their first demonstration in the 1960s, picosecond laser pulses have initiated and defined the area of ultrafast laser physics. Their ability to generate a burst of high-intensity, coherent light has opened up areas of science and enabled the observation of events that would otherwise remain out of the realm of human understanding.

The particular mechanism commonly associated with picosecond pulse generation is mode-locking. These systems are typically complex, bulky and correspondingly expensive. A compact, cheap and robust option that produces comparable pulses would be of great value to the scientific and engineering communities. To this end, we examine the growing area of Q-switched microchip lasers: simple and compact devices that generate sub-nanosecond pulses by virtue of extremely reduced resonator cavity lengths. Incorporation of a passive Q-switch device, a semiconductor saturable absorber mirror or SESAM, enables truly minimal cavity lengths, and therefore minimal pulse durations, to be accessed.

In this thesis we explore the limits of generating the shortest pulses from such microchip lasers. We develop a comprehensive numerical simulation model, based on the laser rate equations, to effectively model SESAM Q-switched microchip lasers. We incorporate additional phenomena such as two-photon absorption (TPA) in the Q-switch and SESAM etalons to derive a complete picture of the abilities of these micro-lasers. We show that TPA will increasingly affect the performance of these lasers, as shorter pulses are generated, and suspect that our model underestimates its effect on our experimental results. We examine the switching dynamics of the SESAM and describe the role of relaxation oscillations in the switching process, as well as demonstrating controlled partial switching. Scaling dependencies between laser component parameters and laser performance are drawn, providing guidelines for development of these lasers. We examine these relationships in experiment and verify the key relationship between short cavities and short pulses. We demonstrate a laser with record short pulses of 22 ps duration by extending the scaling of these lasers to the shortest demonstrated cavity length of 110 μm.

To alleviate the low efficiency associated with lasers using thin gain media, we propose, model and develop an energy-scavenging amplification scheme. We demonstrate that a complete, amplified Q-switched microchip laser system has the potential to rival amplified mode-locked systems in generating few-picosecond, microjoule pulses, although practical validation of this will approach require careful laser engineering.

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When thinking back over the four years that encompassed this project, it is far too easy to offhandedly describe them as having “flown by” and leave it at that. While this statement is not untrue – the time certainly seems to have disappeared quickly – it does not do justice to the sheer volume of experiences I have had since I first hatched the laser-PhD-in-Australia plan in the summer of 2007. Through every single one of these experiences, be they good or bad, easy or tough, I was joined and supported by an entire regiment of people, each lending me their expert hand. In a lot of cases, this expert hand was passing me a beer.

It is probably best to start where I did: with my parents, Pauline and Richard, and my beer-wielding sister, Rhiannon. From growing up in the Welsh countryside, through school and then university, and now to my studies in Australia, they have each supported and guided me at every step, going out of their way to open up every opportunity that could be made available to me and making sure that I made the most of it. One of my earliest and fondest memories is racing Rhiannon to calculate the averages of sets of numbers called out by our dad – our arithmetic skills were well-matched and the competition fierce. Our enjoyment of this exercise is certainly partly to blame for my route to physics, although it doesn't explain why I've never received the correct change after buying a pint from my sister. It has not been easy being so far from my family – even though Mum always (accurately) predicted that I'd never leave university, I think it came as a shock even to her when I upped-sticks for Australia – but I thank each of them for their endless love and support.

Soon after family, come friends. The day I left the UK for Australia, I broke the hearts of a very special group of people: a troupe of young men who have been my best friends for years and decades. Not a week goes by when they don't ask when I'm coming home, often making me jealous with tales of their naughty exploits in my absence. They know who they are, but for identification purposes when we all get caught trying to N-run across Europe, they are: David, Tim, Huw, Simon, Rob, Sam, Nick and Owen. Of course, I couldn't have survived in Australia without picking up some excellent friends along the way: Dan, Dean, Nige, Mike and Carol are stand-out examples of friends who are great under pressure. Providing light entertainment in the office and beyond were Christopher, Simon and Graham, with a special mention to my good friend and lab-mate, Eduardo, who showed me how it was done. Thank you all for the good times.

Heading back to the matter at hand, there are two people whose efforts in this project cannot go unnoticed. Dr David Spence and Associate Professor David Coutts have been my long-suffering supervisors for this project, and deserve some of the fullest thanks I can give. As credited by his first PhD student, Eduardo Granados, David Spence has infinite patience and in addition, has the uncanny and unfailing ability to answer every question in a language or fashion that is immediately understandable to the asker. From a student's perspective, especially for one prone to asking stupid questions (often the same one repeated in different guises), these traits are invaluable in a PhD supervisor. David is gaining more and more PhD students by the month, but prospective students be warned: he promised me a bottle of champagne for when I got my first laser working, then it was for after I'd achieved the shortest pulses, then it was

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