TOWARDS FUNCTIONAL MINIATURIZED LASERS

Thesis by

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In Partial Fulfillment of the Requirements for the

Degree of

Doctor of Philosophy

CALIFORNIA INSTITUTE OF TECHNOLOGY

Pasadena, California

2007

(Defended May 3, 2007)

To my parents Kezhao Zhang and Xiaozhou Chen

ACKNOWLEDGEMENTS

My first thanks go to my advisor Axel Scherer, who provided me the opportunity to work in this exciting field and to be a part of his great research group. I would never forget his generosity for having an Aeronautics student trying out the semiconductor laser projects. Needless to say, his tireless efforts have played an important role in the progress I've made the past few years. Beyond this, I have learned immeasurable amounts from him in both science and technology. Moreover, his patience and constant encouragement are what bring me to the stage today.

I also owe a debt of gratitude to my research mentors Dr. David T Wei and Dr. Tomoyuki Yoshie, from whom I learned most of the research techniques on which my work in this thesis is based. From them, I realized the importance of independent research work.

My great thanks also go to my colleagues. This list includes: Dr. Koichi Okamoto, Dr. Terrell Neal, Dr. Lan Yang, Zhenyu Li, Yan Chen, Ting Hong, and David Henry who have been collaborating with me on all my research work thus far; the undergraduate students Julie Sze, Tom Sze, Xiaoliang Zhu, Jiajing Xu, Victor Liu, Jie He, and Geng Wang who helped me on the experimental work in the sweating summers as well as during some of the terms throughout the years; Dr. Haiquan Yang from Epiworks Inc.; Dr. Yueming Qiu from Jet Propulsion Lab; Dr. Yongqin Jiao, Dr. Chi Ma, Dr. George Roseman, Lin Zhu, Dr. Tao Lu, Hong Zhong, Dunwei Wang, Ke Xu, and Xiquan Cui—all from Caltech—who each helped me out in some part of the experiments; Dr. Joyce Wong and Dr. John Choi, who encouraged me all the time and gave valuable advice. Among them, special thanks to Dr.

Koichi Okamoto, Dr. Terrell Neal, Dr. Lan Yang, and Victor Liu, who helped me a lot in many aspects.

Beyond the few I have just named, with whom I have directly interacted the most, I gratefully acknowledge everyone else in the Nanofabrication group, Maladen Barbic, Marko Loncar, Mark Adams, David Barsic, Ali Husain, Jeremy Witzen, Brett Manue, Sven Matthias, Emil Kartalov, Michael Hochberg, Tom Baehr-Jones, George Maltezos, Chris Walker, Teresa Emery, Guangxi Wang, Saurabh Vyawahare, Uday Khankhoje, Michael Shearn, Jingqin Huang, Sameer Walavalkar, and especially our secretary, Kate Finigan, and our lab coordinator, Dr. Guy DeRose, who have been working hard to enable an efficient working environment. I am so lucky to have spent these years with these great people.

Finally, I would like to thank my advisory board: Dr. Axel Scherer, Dr. Amnon Yariv, Dr. Kerry Vahala, Dr. Changhuei Yang, Dr. Marc Bockrath; and the other members in my candidacy committee: Dr. Demetri Psaltis and Dr. Oskar Painter.

ABSTRACT

In this thesis, nanometer scale semiconductor lasers and micrometer scale polymer based dye lasers are our focus in bringing the miniaturized lasers to applications in data transmission; ultra-small chemical / biological sensors; and ultra-compact spectroscopic sources. Combining the advantage of electrically driven semiconductor lasers and the advantage of a broad emission spectrum of dye molecules would utilize the highly dense multi-functional lab-on-a-chip by integrating microfluidic PCR, microfluidic fluorescent detection system, and compact visible and NIR detectors which are commercially available. On the other hand, in the meantime of pushing the size limit of the laser cavities, new phenomena with the nanoscale lasers enable further exploration and understanding in fundamental physics.

In the first part of this thesis, two sub-micron scale semiconductor lasers are presented. The smallest lasers utilizing the disk structures—with diameters of approximately 600 nm—were realized in the InGaP/InGaAlP quantum well material system at room temperature, featuring ultra-small mode volumes of approximately 0.03 μm^3, and exhibiting single-mode operation at low threshold powers. And the first visible photonic crystal ultra-small mode volume lasers, with cavity volumes of approximately 0.01 μm^3, are realized in the same material system. They are ideally suited for use as spectroscopic sources and both of them can be lithographically tuned from 650 – 690 nm.

In the second part of this thesis, two sub-millimeter-scale polymer-based dye lasers—a poly(dimethylsiloxane) (PDMS)-based mechanically tunable DFB dye laser and a

poly(methylmethacrylate) (PMMA)-based second-order circular grating distributed feedback dye laser—are presented. Both of them are compatible with microfluidic technology, which gives freedom in integrating the lasers with the microfluidic chips. Compared to the soft lithography used in the PDMS-based dye laser, the nanoimprint lithography used in the PMMA-based dye laser would be more useful for fabricating ultra-small dye lasers and enabling mass production in the near future.

At the end of the thesis, a nano-linewidth metal grating mask pattern transferred transient grating (MPT-TG) technique is described as a potential technique using the ultra-small lasers for molecular-dynamics study in solutions.

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