# Graduate

# Research Projects in Photonics

**Engineering Science, Material Science, Physics and Electrical and Computer Engineering**

***Amr S. Helmy Group ECE @ U of T***

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# Beating Quantum Noise Limits in Optical Amplifiers

Traditional amplifiers have added noise that is extra during the amplification process. The added noise is an internal noise from the amplifier, which is unavoidable. Generally, a laser is in the coherent state. This quantum state is not permittable for achieving noiseless amplifier, because the two quadratures have the same quantum noise from each other. In this case, it is not possible to suppress the noise in either quadrature. One of the most important principles in quantum mechanics is the Heisenberg uncertainty (the Robertson–Schrödinger relation), whereby if one can observe the input signal quantum quadrature selectively, which is noncommutative. As such, it is possible to achieve noiseless amplification via a chi-(2) second order nonlinear parametric process if one of the two quadratures is amplified, whilst the other is attenuated at the same time [1].

The noise in one of the quadratures is comparably larger than the orthogonal quadrature, while the minimum uncertainty relationship still holds for both. This kind of quadrature pairs exist in a new quantum state called squeezed state[2][3]. To create squeezed state, we use semiconductor material in III-V AlGaAs as the nonlinear material [4]. Exceptionally high squeezed states had been generated in our BRW waveguide [5]. This lends us opportunities of achieving continuous variable quantum photonic platform that can find applications in quantum computation [6], quantum sensing [7] and imaging. Also, in the classical communication side, where phase sensitive amplifier can be made without extra noise to amplify input signal that is in high demand for long haul communication network. Figure 1 illustrates the device structure, as well as the experimental methods. There are rich potentials in broader fields of characterization of aplifiers performance, as well as design the new waveguide structures to maximize the squeezing/parametric gain.

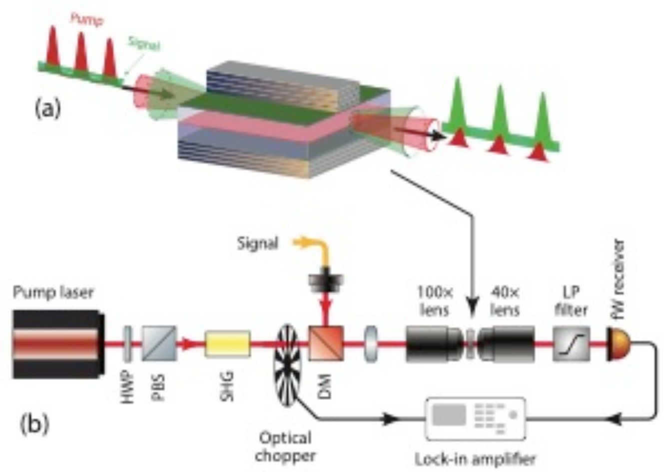



Figure 1: Illustration of experimental setup for generation of squeezed state and phase sensitive amplifier using an AlGaAs waveguide. (a) The waveguide is pumped by a strong pulsed laser that has several orders of magnitude higher peak power than its average power. This ultra-short pulsed pump allows for generation of record high squeezed state. (b) The typical experimental setup for characterization of squeezed state

[1]. C. M. Caves, "Quantum-mechanical noise in an interferometer," Physical Review D 23, 1693–1708 (1981).
[2]. D. F. Walls, "Squeezed states of light," Nature 306, 141–146 (1983).
[3]. R. Loudon and P. Knight, "Squeezed Light," Journal of Modern Optics 34, 709–759 (1987).
[4]. J. B. Han, et al., "Femtosecond second-harmonic generation in AlGaAs Bragg reflection waveguides: theory and experiment," Journal of the Optical Society of America B-optical Physics 27, 1291–1298 (2010).
[5]. Z. Yan, H. He, H. Liu, M. Iu, O. Ahmed, E. Chen, Y. Akasaka, Ikeuchi, and A. Helmy, "Record High Squeezing using χ(2) in AlGaAs Chips," in Conference on Lasers and Electro-Optics, OSA Technical Digest (Optical Society of America, 2019), paper FW3B.5.
[6]. S. Takeda and A. Furusawa, "Universal Quantum Computing with Measurement-Induced Continuous- Variable Gate Sequence in a Loop-Based Architecture," Physical Review Letters 119, 120504 (2017).
[7]. J. Aasi and et al., "Enhanced sensitivity of the LIGO gravitational wave detector by using squeezed states of light," Nature Photonics 7, 613–619 (2013).

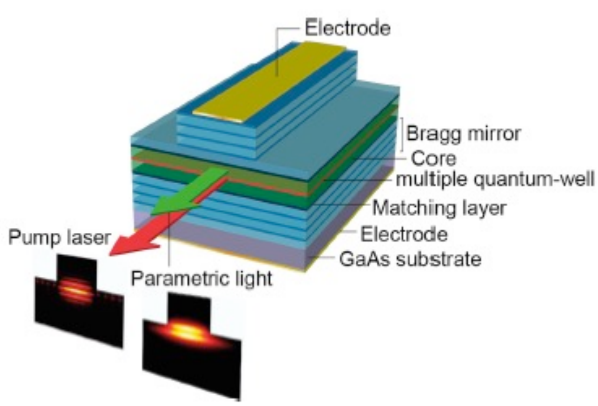
# Quantum and Parametric Processes in Bragg Diodes Laser

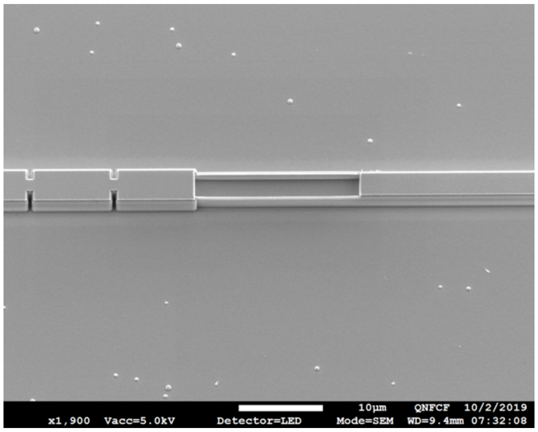
Semiconductor lasers are the most attractive coherent sources available. There is a limited set of suitable materials which can be used for semiconductor lasers generating infrared laser radiation. The proposed research aims to develop compact, inexpensive and tunable coherent sources covering most of the infrared region of the spectrum, while utilizing nonlinear and quantum effects in these cavities for numerous sensing and data communication applications.

Recently our group demonstrated a new class of lasers called Bragg laser diodes.[1,2] The unique design of these lasers allows extension of frequency range occurrence using nonlinear frequency conversion processes such as sum-harmonic generation and difference frequency generation inside the cavity of the laser.[3,4] In order to increase the efficiency of these nonlinear process it is imperative for the laser to achieve single mode emission with high photon density inside the cavity.

The project involves the design of high peak power, integrated near infrared semiconductor lasers, semiconductor laser characterization and device spectroscopy and monolithic integration of monolithic lasers with nonlinear elements for the realization of monolithic optical parametric oscillators. The scope of the project will also include characterization of the ring lasers which allow high photon density inside a facet-less cavity, while keeping a small form factor.

Candidates with doctoral degrees in physics, applied physics, electrical engineering or any related discipline will be considered. The post encompasses a strong experimental component, but some analytical skills will be required.



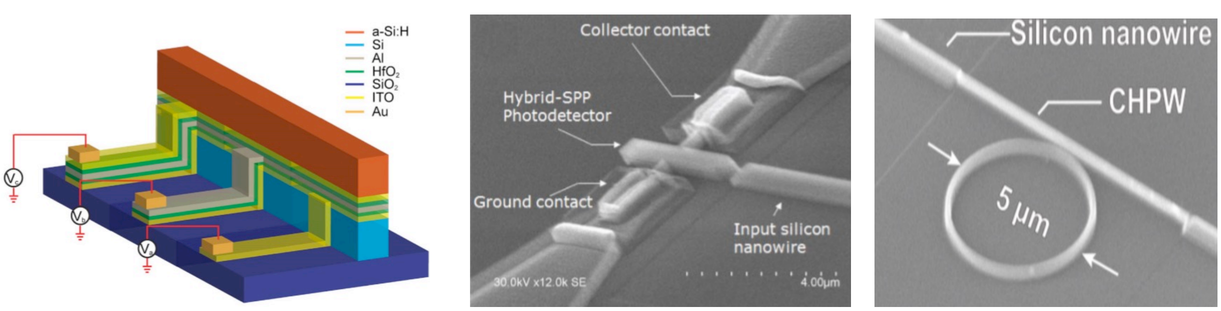

1. B. J. Bijlani and A. S. Helmy, "Bragg reflection waveguide diode lasers," Optics Letters, Vol. 34, No. 23, pp. 3734-3736, 2009.
2. C.Z. Tong, B.J. Bijlani, S. Alali, and A.S. Helmy, "Characteristics of Edge-Emitting Bragg Reflection Waveguide Lasers," IEEE Journal of Quantum Electronics, Vol. 46, No. 11, pp. 1605-1610, 2010.
3. B.J. Bijlani, P. Abolghasem, P. Reijnders, A.S. Helmy, "Intracavity parametric fluorescence in diode lasers," Proceedings of Lasers and Electro-Optics (CLEO), 2011.
4. Meng Lon Iu, N. Zareian, D. Kang, E. Chen, P. Charles, B. Janjua, Y. Akasaka, T. Ikeuchi and Amr S. helmy, "Efficient frequency conversion over S-C-L-U bands within an electrically pumped chip using $\chi^2$", Photonics Conference (IPC), special session, Buena Vista Palace, Orlando, FL, USA (2017).

# Plasmonic integrated circuits

As interconnect latency and power consumption have become bottlenecks for speed in integrated electronic circuits, the overall speed of central processing units (CPU) for computers are reaching conventional limits. One possible solution to mitigate this bottleneck is the employment of photonic circuit, which can be the technology of choice for high-speed telecommunication and routing of data thanks to its high information bandwidth and processing speed. For future highspeed interconnect, photonic devices thus are capable of complementing the lack of capability of electronic devices to achieve high performance. However, the physical footprint of the photonic devices is limited by the optical diffraction limit. The significant scale differences involved between nanoscale transistors and micron-sized photonic element therefore limits the potential for denser integration in optoelectronics circuit.

Plasmonic waveguide based on surface plasmon polariton can lead to the formation of optical mode that is not diffraction limited. However, due to ohmic dissipation that is inherent to most plasmonic materials in optical frequency, the propagation length of plasmonic modes is typically limited to few tens of micrometer. Our project aims to develop a plasmonic platform that can promise the scale down of the physical size of photonic integrated components to nanoscale, while maintaining long propagation length. The proposed architecture thus can offer a design building block for optical interconnect components with enhanced performance. Recently, our group has demonstrated plasmonic modulator [1], photodetector [2], and ring resonators [3].

The design of our plasmonic waveguide can be facilitated by commercial simulation software. Promising design will be further fabricated and the device performance will be tested. Students involved in this project can learn about devcie design as well as device characterization techniques. Other than interconnects, our plasmonic structure can also offer a nanoscale waveguide environment for many other physics and engineering applications. Students with engineering science, ECE or physics backgrounds will be particularly suited for the project.




Left to right: plasmonic modulator, photodetector and resonator.

[1] C. Lin, Scientific Reports, 5, 12313 (2015).
[2] Y. Su, Optica 4, 1259, (2017).
[2] Y. Su, Science Advance 5, eaav1790 (2019).

# Optofluidic Raman Spectroscopy for Process-Free Analysis of Fluids in Healthcare and the Environment

Our fingers have fingerprints that are unique to each one of us. But did you know that every material also has a unique chemical fingerprint of its own as well? State-of-the-art systems for portable and sensitive fingerprinting of liquids, gases or aerosols are based on highly purpose-specific sensors which require prior knowledge in order to select appropriate sample preparation methods. This project addresses increasing needs for cost-effective, handheld portable instruments that enable rapid detection, identification, and measurement of a wide variety of fluids outside of the controlled lab.

Raman Spectroscopy is a powerful optical technique that captures "fingerprints" of materials through detecting different colours of light scattered from the material. Standard Raman instrumentation is severely limited for analysis of liquids, gasses, and aerosols, due to inefficient optical designs. These limitations prevent it from being widely adopted in industries such as environmental monitoring and biotechnology, where most samples are gasses, liquids or aerosols. In this project we expand on a novel technique which we have developed to improve the sensitivity of Raman systems for liquid solutions, giving it the power to additionally detect, identify, and measure gases and aerosols. A miniature optofluidic device increases the generation of Raman scattering light as well as collection efficiency, improving sensitivity by more than 1000 times compared to conventional Raman spectroscopy, and isolates delicate or harmful fluids from the environment. This sensitivity improvement has enabled us to detect detailed structures of nanoparticles with the size of a few nanometers, ocular proteins at concentration below 50 μM [2], and atmospheric gases in the ppm regime.

Students in this project will investigate the use of a chip based optofluidic platform for use in Raman spectroscopy. The first step will involve design, fabrication, and characterization of different optofluidic chips with pre-fabricated waveguides to optimize the signal sensitivity, compatibilities, and usability. In the second step, students will then learn and apply lithographic techniques to fabricate different custom waveguide designs on-chip. Students will learn to use the advanced research-grade Raman system in the Characterization lab in the Sandford Fleming building and test the final optofluidic chips using the system.

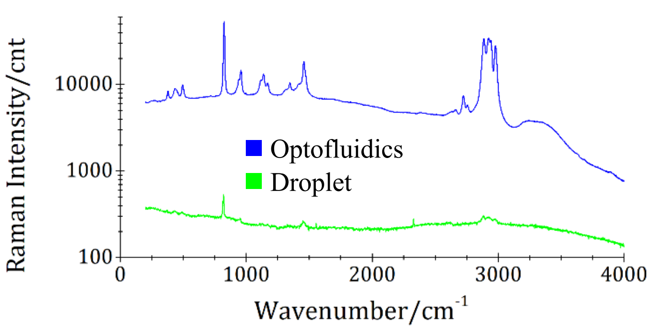



Figure 1: Raman sensitivity enhancement via optofluidics

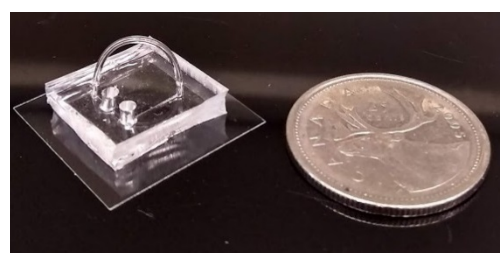


Figure 2: Micro-opto-fluidic device

1. Herman M. K. Wong, Mohsen Kamandar Dezfouli, Simon Axelrod, Stephen Hughes and Amr S. Helmy, Nanoscale plasmonic slot waveguides for enhanced Raman spectroscopy, Phys. Rev. B 98, 085124, 2018.
2. E. E. Storey, D. X. Wu, and A. S. Helmy, J. Ram Spectr. 2019.
3. Herman M. K. Wong, Mohsen Kamandar Dezfouli, Simon Axelrod, Stephen Hughes and Amr S. Helmy, Theory of hyperbolic stratified nanostructures for surface enhanced Raman scattering, Phys. Rev. B 96, 205112, 2017.