論 文 の 内 容 の 要 旨

論文題目　Research on wavelength-scale metal-clad semiconductor lasers and their waveguide coupling
（波長スケール金属共振器半導体レーザとその導波路結合に関する研究）

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Large scale integrated electronic circuits have been developed year by year in Moore's Law, and close to fundamental physics limit now. Signals transferred through electrons in wires would get distorted at high communication speed. This is limited by the transmission characteristic of wires. One of the promising solutions is believed to be using light to carry signals instead of electrons. However, conventional photonic devices are three orders larger than electronic devices. This mismatch make the hybrid integration of photonics and electronics very challenging.

Miniaturization of photonic devices is an important factor for future high speed signal processing. In this thesis, I focused on nano-laser, which is extremely important for optical communication systems. It is key technology to achieve on-chip optical interconnects. In 2007, first metal-clad laser was demonstrated experimentally. Its size was 260 nm in diameter, on deep sub-wavelength order, considered as high potential candidate in on-chip high-density photonics.

Metal-clad laser has merits of strong light confinement, good thermal dissipation, Purcell effect enhancement and high-speed operation. However, making a metal-clad laser is very challenging because metal is lossy at room temperature, leading to higher threshold than expected. In addition, quality of metal film is poor, further degrading the performance of laser. Since light is easily scattered by rough surface, imperfection of fabrication is a problem to realize such device as well.

Great efforts were made to promote this topic. In our lab, capsule-shaped cavity was discussed numerically so far. By changing the planar mirror of conventional Fabry-Perot cavity into curved mirror, the resonating mode is constricted at center of cavity. As a result, overlap with metal is decreased, metal induced loss is reduced.

I improved the fabrication process, demonstrated capsule-shaped cavity experimentally. In order to confirm the idea of new design, optical pumping was used instead of electrical pumping which may induce heating problem. The cavity has a dimension of 1.6 μm ×1.0 μm. It achieved lasing at room temperature under pulsed optical pumping. Light-in light-out plot shows that capsule-shaped cavity has higher slope efficiency and higher side mode compression ratio at same pumping power than rectangular cavity.

Based on this result, I further discussed waveguide-coupled wavelength-scale metal-clad laser. Metal-clad cavity's Q factor is as low as several 100s. Coupling with waveguide will further degrade the Q factor, make it difficult to start lasing. So far waveguide-coupled wavelength-scale LED has been reported but waveguide-coupled wavelength-scale laser is not yet. Capsule-shaped cavity originally has higher Q factor than rectangular cavity, providing advantage in coupling with waveguide. I discussed the design of waveguide-coupled wavelength-scale metal-clad laser using capsule-shaped cavity numerically. By analyzing the power loss in the optical oscillation, it is clear that engineering the width of joint between cavity and waveguide can affect overall Q factor to some extent. This provide a relative easy way to design the device. I tried to fabricate the device with different designs, and spontaneous emission was observed from output waveguide. It is evidence that light is coupled into waveguide successfully.

For future improvement, firstly, better plasmonic material other than silver or gold is required, which has high reflectivity at infrared wavelength and low absorption loss. Secondly, making the device on silicon on insulator (SOI) substrate instead of InP substrate could enhance Q factor of cavity and coupling efficiency with waveguide. Lastly, new active material with higher gain than current semiconductor is preferred in nano-laser to achieve lasing under limited volume.