論 文 の 内 容 の 要 旨

論文題目　　Capsule-shaped metallic InGaAs/InP cavity laser for photonic integrated circuits−proposal, simulation and demonstration

（光集積回路に向けたカプセル形状InGaAs/InP金属共振器レーザの研究−提案，解析，実証）

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In this dissertation, a novel metallic semiconductor laser structure of “capsule-shaped cavity” is proposed, simulated and experimentally measured for the first time, aiming at reduction of the metallic loss and improvement of the cavity property. By introducing cylindrical ends with optimal curvature at both ends of the cavity, Gaussian-like mode profile can be formed inside, which drastically reduces the field overlap at the metallic sidewalls and thus lowers down the optical loss. As a result, the cavity *Q* factor can be improved effectively. Both numerical simulation and experimental measurement of this research demonstrate the advantage of the capsule-shaped structure for metallic semiconductor lasers, which can miniaturize the device size further and can be used in potential applications in photonic integrated circuits (PICs).

In Chapter 1, background of this research is introduced briefly. As the trend of miniaturization of photonic devices in large-scale PICs in recent years, metallic cavity structure is widely studied and discussed for shrinking laser size. The challenge to be overcome is the high loss caused by the metal-clad in the laser structures, and previous studies are focused on the improvement of fabrication and use of high-gain materials. In order to improve the property of metallic semiconductor lasers further, a new idea which is independent on the previous work is necessary, and therefore

In Chapter 2, the state of the art of metallic cavity lasers is investigated, including the cavity structures, lasing modes, metallic losses, and pumping conditions. On the one hand, the whispering-galley (WG) mode and Fabry-Perot (FP) mode, corresponding to circular and rectangular cavities, have advantages and disadvantages respectively, and both of them are experimentally demonstrated in recent years. On the other hand, considering the potential applications of metallic lasers in PICs, the ease of waveguide coupling and the compatibility with other devices are two important issues, for which the FP-mode based cavity is more suitable. To reduce the high loss at the metallic sidewalls in the conventional rectangular FP cavity, a new design of capsule-shaped cavity with curved mirrors is proposed, which can support Gaussian-like resonant mode that is far away from the sidewalls.

In Chapter 3, theoretical analysis of the metallic InGaAs/InP cavity lasers is done by the rate equation theory, and formulations of threshold gain and threshold current are analytically derived. To estimate these values, cavity Q factors and confinement factors should be calculated. Waveguide theory is used for an intuitive understanding and analysis, while some important issues such as the radiation field, mode pattern and precise cavity Q factor cannot be taken into account by this two-dimensional theory. Then three-dimensional (3D) finite-difference time-domain (FDTD) simulation method is briefly introduced, which is necessary for the proposed structures. Near to far field transformation is also included in this chapter, as it is an important issue in both practical applications and measurements.

In Chapter 4, series of 3D-FDTD simulations of capsule-shaped metallic cavities is carried out and discussed in details, including Q factors, mode patterns, confinement factors, threshold gains, threshold currents, radiation efficiency, waveguide coupling efficiency and far field radiation. It is numerically confirmed that by introducing an optimal capsule-shaped structure, *Q* value can be improved above 50%, compared to a conventional rectangular cavity. Besides, the threshold gain and current can be reduced exponentially, by the proposed design, into a practical level that can be possibly achieved by III-V semiconductor materials. And other issues such as size shrinking effect, ease of waveguide coupling, external radiation efficiency are also discussed in this chapter. All these simulation results numerically demonstrate that the proposal in this dissertation is suitable and efficient for the ultra-small lasers for the applications in PICs.

In Chapter 5, fabrication of the capsule-shaped metallic InGaAs/InP cavity is done for the first time. Extra loss can be introduced to this structure by imperfect fabrication process, which worsens the quality and property of the cavities. To avoid these factors, the process techniques are studied and improved for a better fabrication, especially in the process such as dry etching and metal deposition.

In Chapter 6, PL characterization of fabricated cavities is measured and analyzed. All the observed spectra demonstrate the *Q*-factor enhancement effect of capsule-shaped structure, and up to 4-fold improvement is achieved experimentally, compared with a conventional rectangular cavity. All the measured results are consistent with 3D-FDTD simulation prediction, and verify the effectiveness of introducing optimal curvature at the cavity ends

In Chapter 7, a brief conclusion of this dissertation is done. From all the simulated and experimental results, it is clear that the capsule-shaped metallic InGaAs/InP cavity structure is really suitable for the light source in PICs. This new design can reduce the high loss in the conventional metal-clad lasers effectively, and achieve higher cavity *Q* factor than that of the conventional structure. Besides, it is relatively easy to be coupled into an integrated waveguide, and is compatible with other devices in PICs. Thus, it can be concluded that this proposal of capsule-shaped cavity is an essential component of the large-scale PICs in the future.