電流注入型金属キャビティレーザの数値解析

Numerical Investigation on Electrically Pumped Metallic Cavity Lasers

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1. Introduction

During the last decade, subwavelength metallic cavity lasers have drawn enormous attention due to their potential application in ultra-compact photonic integrated circuits and on-chip interconnects [1,2]. Aside by conventional rectangular cavities, we have previously demonstrated the Q factor improvement effect of capsule-shaped lasers with less metallic loss [3]. However, electrical and thermal analysis are not paid enough attention even though self-heating turns out to be an important issue [2].

In this paper, we numerically investigate the lasing property of different types of metallic lasers under electrical injection. Electrical and thermal simulations are carried out consistently, through which we confirm enhanced performance of our design by introducing a thin InAlAs electron blocking layer.

2. Device Structure

The schematic of laser is shown in Fig. 1. Capsule structure is utilized for enhanced Q factor [3]. Unlike conventional lasers, high carrier densities with optical gain over 1000cm^{-1} are usually required for nanoscale lasers, which induces large leakage current and significant heating. To solve this issue, we propose to insert a 10nm $In_{0.52}Al_{0.48}As$ electron blocking layer between the InGaAs active region and the bottom InP region. The entire device is encapsulated with a thick silver layer that functions both as mirrors and an efficient heat sink [2]. At last, the substrate is removed to increase light confinement.

3. Simulation Results

We analyze the device with 2D simulation assuming cylindrical symmetry for simplicity. We compare two structures shown in Fig. 2, one with the InAlAs blocking layer and another without this layer. Poisson and lattice temperature equations are solved consistently using a thermodynamic model. Due to a larger conduction band offset between InAlAs and InGaAs, electron leakage currents are substantially reduced as shown in Fig. 2(a). This enables easier carrier accumulation and thus larger carrier densities in the active region as displayed in Fig. 2(b). 17% increase of carrier density is observed at 2mA injection, corresponding to improvement of optical gain from 1230cm^{-1} to 1390cm^{-1}.

Fig. 2(c) plots the stimulated emission rates for the two cases stated above. In effect, the blocking barrier halves the lasing threshold and facilitates a 6 times larger emission rate at 3mA. Fig. 2(d) shows the temperature distribution at 1mA for the structure with InAlAs layer, where auger recombination and hole joule heating dominate among all heat sources. Owing to the reduced threshold current and sufficient heat dissipation by silver sink, temperature rise keeps moderate when lasing is built up.

To find the optimal structure, optical mode analysis should be combined in the future.

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[2] K. Ding et al, Light: Science & Applications, **1**, e20 (2012)
[3] B. Zhang et al, Phys. Status Solidi, **5**. (2015)

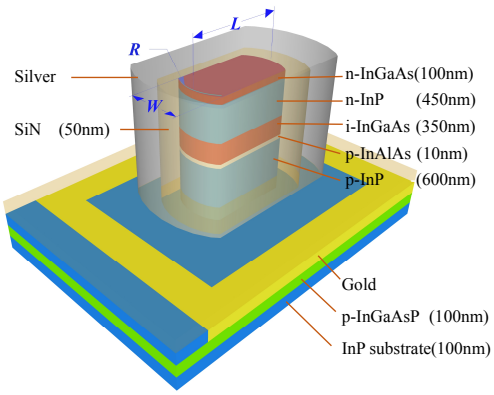

Fig. 1 Schematic of electrically pumped laser

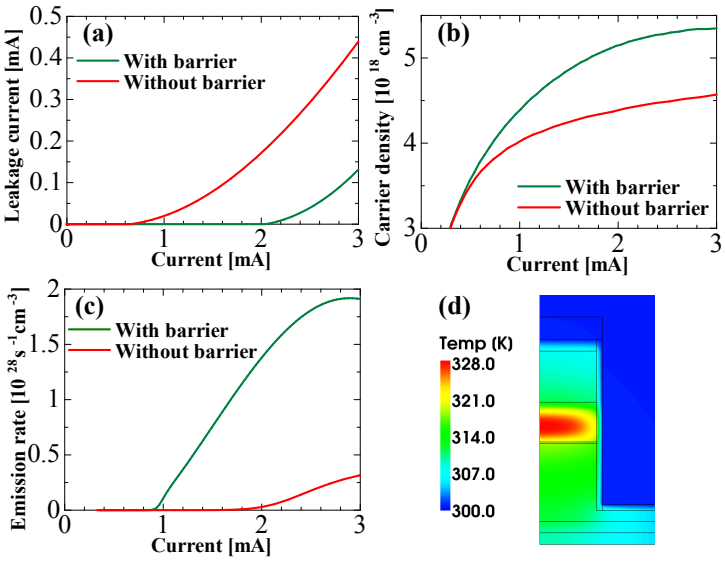

Fig. 2 Simulation results of leakage current (a), carrier density (b), stimulated emission rate (c), and temperature distribution (d).