Optical gain in InGaAs/GaAs self-assembled quantum dots and its effect on optical devices

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Semiconductor quantum dots are promising new materials for optical devices in the future photonic technology. Research on quantum-dot optical devices is now being accelerated owing to the development of self-assembled quantum dots [1]. A key to their practical application is the optical gain. In this paper, we present our recent understanding of the optical gain of self-assembled quantum dots, and discuss its effect on optical devices.

1. Theory of quantum-dot optical gain: We derived formulae for the quantum-dot optical gain by taking into account spatial isolation of quantum dots, homogeneous broadening due to dephasing of polarization, inhomogeneous broadening due to size fluctuation, and the discrete energy states.

2. Optical gain measurements by Hakki-Paoli method: We measured material gain by Hakki-Paoli method as a function of the total injected carrier density in two-types of quantum-dots (Fig. 1(a) and (b)) [2]. The maximum optical gain of the ground state was 200-400 cm-1 . The solid lines are theoretical calculations, showing a good agreement with the measurements. We also evaluated alpha parameters to demonstrate that they are less than one at the lasing wavelength .

3. Effect of homogeneous broadening of single-dot optical gain on lasing spectra [3]: Lasing spectra around the threshold are known to depend on temperature; broad lasing emission over several tens meV at 80 K, and a narrow lasing line at room temperature. We could completely reproduce such lasing spectra by simulation taking into account the homogeneous broadening and inhomogeneous broadening (Fig. 2). The homogeneous broadening, which is almost delta-function like at 80 K, increases as temperature increases. The magnitude of homogeneous broadening was evaluated to be 16 - 19 meV at room temperature from the experimental lasing spectra, and also from the pump-probe measurements in the traveling type waveguide with the quantum-dot active region under population inversion. These broadening indicates the dephasing time to be 70-80 fs.

4. Ultrafast gain recovery: Another physical property found in the pump-prove measurements in the traveling-type waveguide was the ultrafast gain recovery; the transmitted intensity of the time-delayed probe beam recovered with a time constant of 1.8 ps. This is striking since 1.8 ps is more than 100 times faster than in quantum wells or bulk semiconductors, suggesting the possibility of ultrafast semiconductor optical amplifiers (SOAs).

5. Effect on quantum-dot optical devices: Based on the knowledge mentioned above, we discuss a design of high-speed low-chirp quantum-dot lasers. Also, we propose the quantum-dot SOAs as a new device, and present an operation theory to show its promising features.

References

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[3] M. Sugawara et al, Phys. Rev. B 61, 7595(2000).
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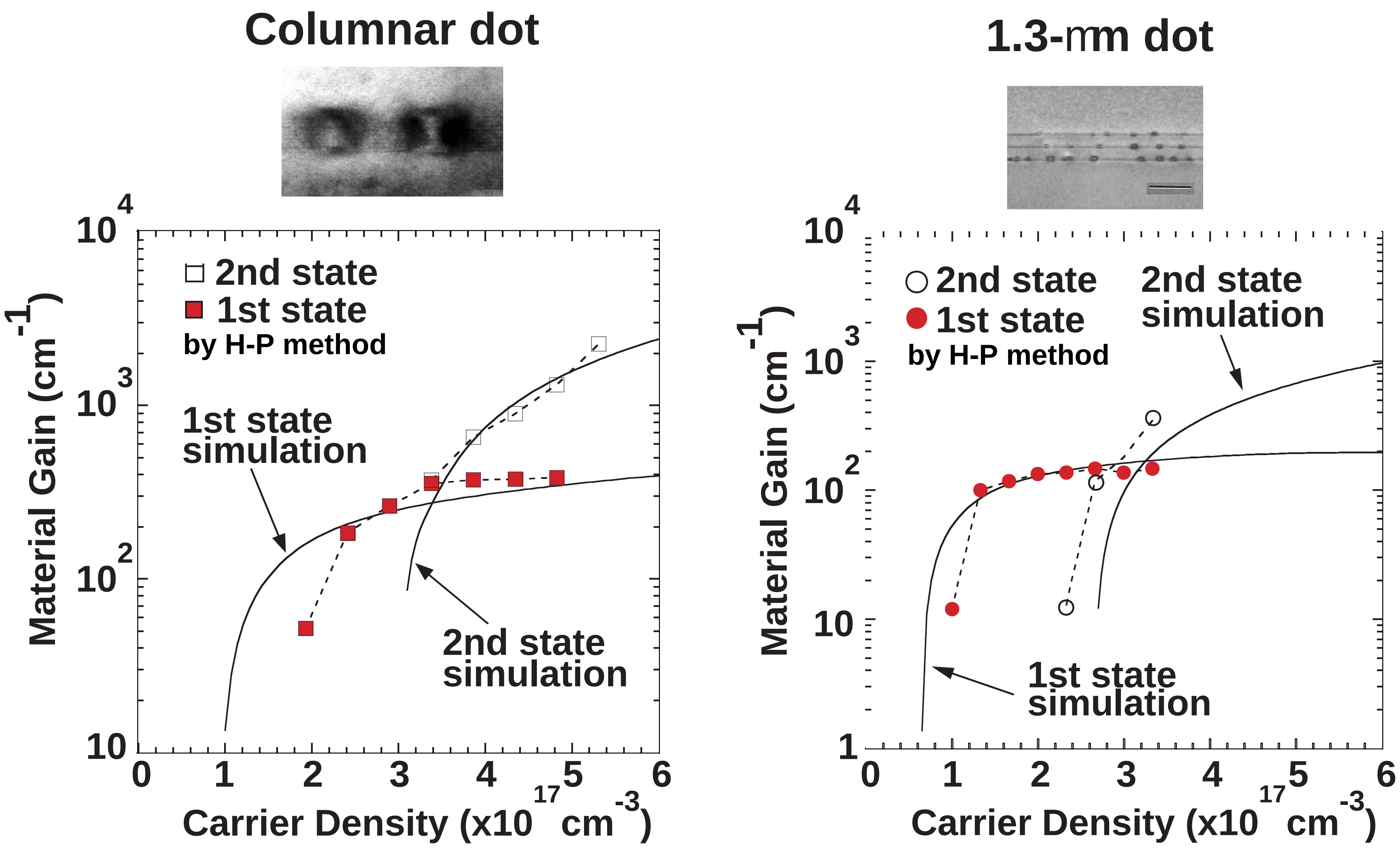

Figure 1 Optical gain measured by Hakki-Paoli method

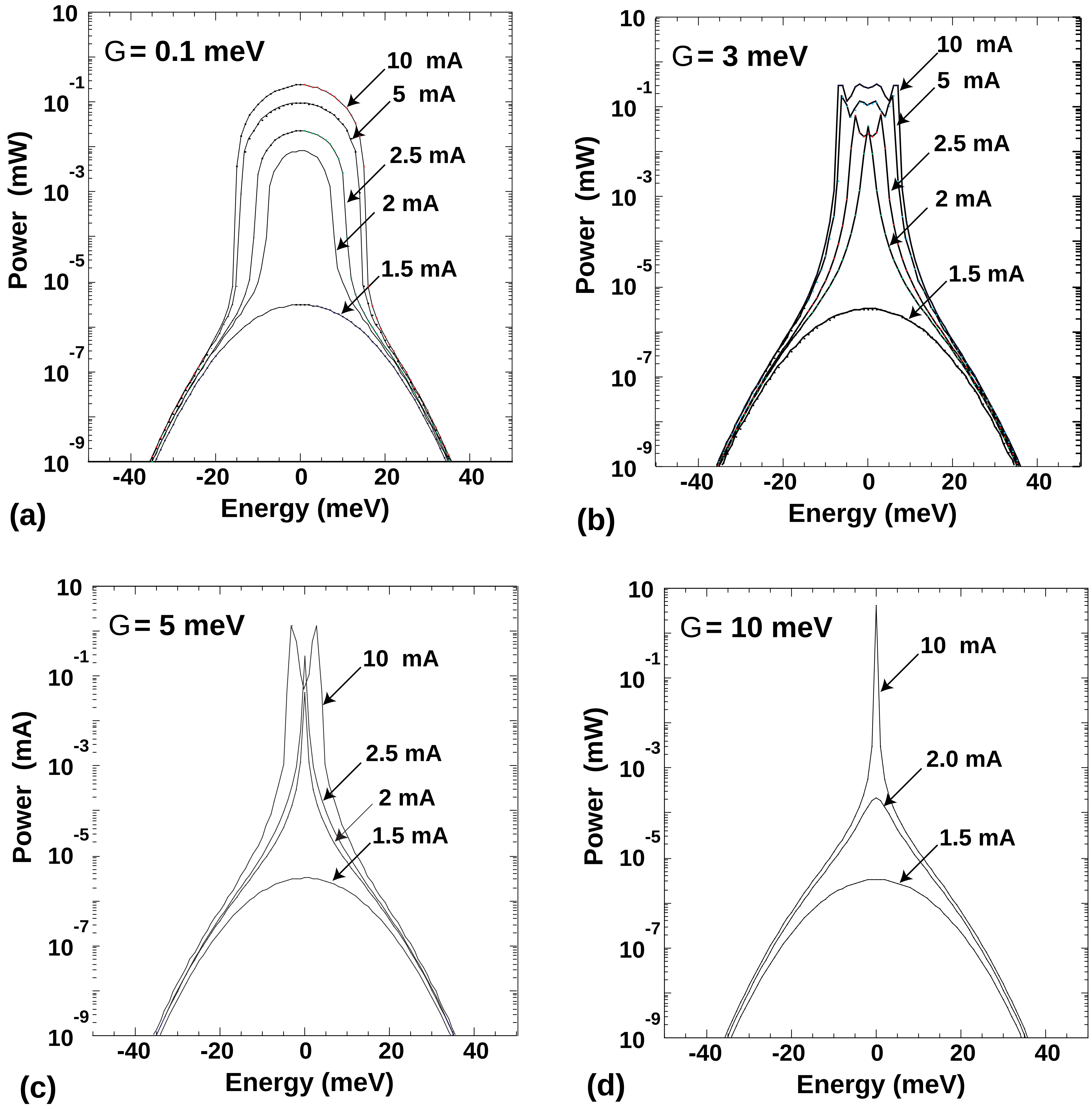

Figure 2 Calculated lasing spectra for various homogeneous broadening, G