New Proposal for Monolithic Terahertz Quantum Cascade Laser Array

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***Abstract*—A novel scheme of monolithic terahertz quantum cascade laser array based on a two-section coupled-cavity is proposed. It is found that the coupled laser system can be operated in phase-locked mode. Our study may inspire future investigations aiming for single-mode high-power THz sources and extend the applications of THz QCLs.**

I. Introduction

AMONG the various methods of generating coherent THz radiation, quantum cascade laser (QCL) as compact and convenient device is the most promising candidate due to its novel operation principle and attainable performance. Although great successes have been achieved during the past decades, the inability to achieve high output power with good phase coherence limits their applications. A means of achieving this end is to couple an array of THz QCLs. Based on injection locking theory, including master-slave, external-cavity and cross-injection locking, semiconductor diode laser arrays with improved beam quality and raised output power have been demonstrated. In contrast to their diode laser counterparts, QCLs have been recently demonstrated to be intrinsically stable against optical feedback[1], and dynamically stable in the entire locking region when they are optically injected[2]. Researchers attribute these superior characteristics to the high value of the photon to carrier lifetime ratio and the negligible linewidth enhancement factor of QCLs. Therefore, in order to promote the output power of THz QCLs, we need to understand how to take the advantage of the intrinsic stability in the design of THz QCL arrays.

Here, we propose a novel scheme of THz QCL array. The device comprises a two-section coupled-cavity[3]. THz QCLs are integrated in one section of the device (the lasing section), which is electrically biased above threshold, while the other section (the coupling section) is biased blow threshold which provides the opportunity of thermal or electrical tuning of the coupling between QCLs, as shown in the lower panel of Fig. 1 (a). To understand the locking of the array in this scheme, we begin with the coupling of two lasers by the unbiased cavity. Considering both of the cross and optical injections confined in the coupling section, we investigate the locking conditions and stability properties, and analyze the far-filed beam quality.

II. Results

In our analysis, we consider two identical THz QCLs coupling to the coupling section, as depicted in the upper panel of Fig. 1 (a). The dynamic process of the system is equivalent to mutual coupling between the two QCLs with optical feedback through external-cavity for each laser. Based on the dynamic coupled mode equations, the stationary solutions of Δf_1 and ΔN_1 for different locked phase of the field $E_1(t)$ relative to $E_2(t)$ is calculated and plotted in Fig. 1(b), where Δf_1 is the detuning between the free-running laser 1 and the coupled laser system, and ΔN_1 is the change of carrier number difference between the upper and the lower levels of laser 1. With the stability analysis of the dynamic equations, we find that the QCLs can be coherently operated in phase-locking modes (in-phase or out-of-phase indicated). As an example in Fig.1(b), the array is operated in out-of-phase mode benefiting maximally from the coupling ("minimum-threshold or maximum-gain" mode).

Figure 2 gives the calculated far-field intensity distribution of the in-phase and out-of-phase phase-locked modes, respectively, showing larger output power and smaller divergence angle compared with individual lasers.

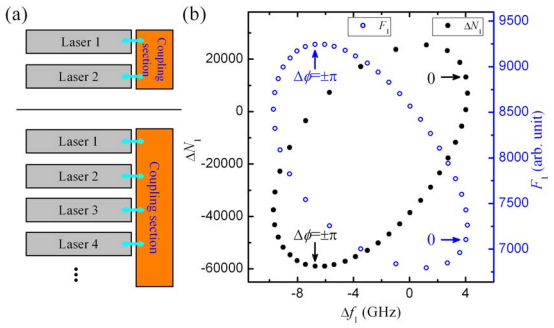

Fig. 1. (a) Scheme of THz QCL arrays. (b) Location of the steady-state solutions in the (Δf_1, ΔN_1) and (Δf_1, F_1) parameter spaces. The arrows indicate the phase-locked modes..

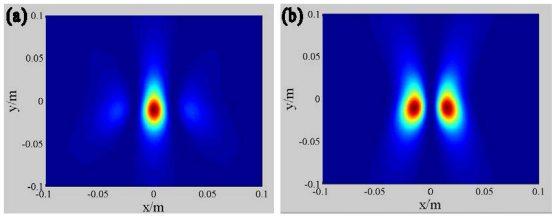

Fig. 2. Far-field intensity distribution of the in-phase (a) and out-of-phase (b) locking modes.

III. Summary

A novel scheme of THz QCL array based on a two-section coupled-cavity is proposed. Our study may inspire future investigations aiming for single-mode high-power THz sources and extend the applications of THz QCLs.

References

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