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論文題目	Three-dimensional Coupled-wave Analysis of External Reflection in Photonic Crystal Lasers （フォトニック結晶レーザにおける外部反射の三次元結合波理論による解析）		

（論文内容の要旨）

This work presents a three-dimensional coupled-wave analysis on the effects of external reflection in large-area, high-power, single-mode band-edge photonic crystal (PC) lasers, and furthermore applies such reflection toward the development of novel edge-emitting PC lasers.

The first chapter introduces the research background and unique functionalities of the PC laser, as well as the forthcoming contributions of the present work to its development. Until now, only PC lasers with negligible reflection at the periphery of the PC have been considered. However, the application of finite reflection to this periphery is expected to enhance various laser characteristics, such single-mode stability, as well as enable the development of a novel, edge-emitting PC laser. This work presents a theoretical analysis of such external reflection using three-dimensional coupled-wave theory (3DCWT).

The second chapter outlines the operating principle, device structure, and semi-analytical 3D coupled-wave model of a near-infrared PC laser. Resonance at the Γ_2 band edge of the embedded square-lattice PC of this laser is considered. External reflection is introduced into the semi-analytical model as the boundary conditions of a set of four differential coupled-wave equations. The chapter closes with the derivation of optical loss from the edges and surface of the PC.

The third chapter opens with an analysis of PC lasers featuring conventional circular air holes in order to simply and concisely explicate the effects of external reflection on the resonant mode. This analysis reveals that the frequency, threshold gain, and profile of the resonant mode depends on the reflectivity and reflection phase at the boundary, and that the suitable design of the reflectivity and reflection phase can widen the threshold gain margin between the lowest-threshold (lasing) and next-lowest-threshold (competing) modes and thereby stabilize single-mode operation. Furthermore, external reflection is applied toward the design of an edge-emitting PC laser, upon which efficient, yet weak emission from a single edge is achieved.

The fourth chapter aims to increase the emission strength of an edge-emitting PC laser by adopting a twin-hole PC design. This twin-hole design suppresses the

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backward diffraction of the resonant mode, which flattens the mode profile and consequently strengthens the single-edge emission by over a factor of ten, albeit at the cost of higher optical loss from the surface of the PC. Separately, an analysis of external reflection in a state-of-the-art surface-emitting PC laser with right-angle-isosceles triangular air holes is performed. This surface-emitting laser does not typically feature a current confinement structure, which is useful for enhancing the electrical-to-optical power conversion efficiency of the laser. The analysis is performed in anticipation of the optical reflection that such a confinement structure will bear on the resonant mode.

The fifth chapter is devoted to enhancing the emission efficiency of an edge-emitting PC laser by shifting the point of resonance from the Γ_2 band edge to the M_1 band edge. At the M_1 band edge, emission from the surface of the PC is forbidden, so a higher edge emission efficiency is expected. Upon expanding 3DCWT to the M_1 band edge, a PC with four air holes within its unit cell and external reflection at three of its boundaries is considered for achieving (1) single-mode, (2) high-power, and (3) efficient single-edge emission. Although strong emission from all edges and zero surface emission is achieved by virtue of M-point resonance, the simultaneous satisfaction of the above three performance metrics is revealed to be difficult due to weak two-dimensional coupling of the resonant mode, which precipitates competition between the lasing and competing modes at even moderate edge reflectivities and hence degrades mode discrimination.

The sixth chapter summarizes the results of the preceding four chapters and outlines the prospects of future research on external reflection in a PC laser. The design of realistic reflectors with tunable reflectivities and reflection phases, as well as strategies for enhancing the performance of an edge-emitting PC laser are proposed as two future research topics. In particular, tunable reflection is expected be possible with distributed Bragg reflectors or high-order PCs, and the mode discrimination of an edge-emitting PC laser is expected to improve using a triangular-lattice PC, which ought to have intrinsically stronger two-dimensional coupling than the square-lattice PCs considered in this work.