Spatial behavior of whispering-gallery “wedge” mode in optical microcavities

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論 文 名　：Spatial behavior of whispering-gallery “wedge” mode in optical microcavities
（マイクロ光共振器におけるウィスパリングギャラリー「ウェッジ」モードの空間挙動に関する研究）

区　　分　：甲

論　文　内　容　の　要　旨

Research on whispering gallery mode(WGM) microcavities is drawing more and more attention in recent years. The WGM microcavity confines light by total reflection on the boundary surface of a circular or a spherical dielectric material, so it possesses characteristics of a high quality factor(Q-factor), a low optical loss, a relatively large mode volume etc. As representative of the widely studied WGM microcavities, micro-3D geometries such as microspheres, microrings and microdisks are the mainstream structures. In the research of WGM microcavities, researchers are devoted to the realization of high Q-factor, the fabrication of high-precision complex 3D optical structures, and WGM microcavities based applications such as low-threshold lasers, optical frequency combs, high sensitivity sensors etc.

In this research, the author participated in the work reported for the first time in the world about simple fabrication of self-forming WGM microdisk laser by using ink-jet technology as a unique fabrication method (coauthor). Based on the above achievement, this specific microdisk made by room temperature ink-jet method was found that the circumferential portion which confines the light of the microdisk possesses an acute edge thinned on the taper, and the WGM light in the microdisk circles slightly inner than the edge of the microdisk. The author named this new mode as whisper-gallery "wedge" mode(WGWM) and studied its spatial behavior.

Most of lithography method fabricated WGM microcavities possess vertical edges, so the spatial position hardly change in WG polarization modes and optical gained modes from the WGM microcavity. However, the WGWM laser fabricated by the author showed differences in the lasing wavelengths depending on the operating conditions, and the differences were inferred to be related to the spatial positions of the WGWM (especially the circumferential diameter of WGWM light propagation path). Research on external factors affecting the spatial position of the WGWM is expected to have important knowledge as various advanced applications such as mode position based wavelength control and external coupling control. However, few research have studied the effects of external factors on the spatial position of WGWM, especially on the wet-process fabricated microcavity.

In this thesis, the effects of various factors on the spatial position of WGWM were mainly explored and analyzed. The effects of edge angles on the spatial position of WGWM were experimentally and theoretically demonstrated with ink-jet printed microdisk lasers.

Furthermore, the effects of gain intensity on spatial position of WGWM was demonstrated experimentally by using quantum dots(QDs) doped microdisk and theoretically by numerical simulation. These results are expressed as following in detail.

Firstly, the spatial position of WGWM is sensitive to angle change was experimentally demonstrated by the ink-jet fabricated microdisk with an acute edge, and theoretically demonstrated with a numerical simulation. In order to clarify the correlations of the lasing wavelength shifts in the LDS 798 dye doped and the Rhodamine 590 doped WGWM microdisk laser, two microdisks laser with different edge angles are experimentally fabricated and characterized, meanwhile the WGWM field cross-sections of different cavity edge angles were numerically simulated by Mark Oxborrow's model in COMSOL software. As a result, the spatial position of WGWM moved to inside of microdisk along the radius direction with decreasing of edge angle, and the TM mode moved more significantly than the TE mode.

Secondly, a prototype WGM microring laser with a perpendicular edge based on a ring-shaped groove platform was experimentally fabricated as benchmark sensor, and a prototype WGWM microdisk laser sensor with an acute edge was successfully demonstrated. In order to lay the foundation of WGWM sensor, temperature sensors were successfully developed by the R6G-doped SU-8 and R6G-doped TZ-001 normal WGM microring lasers with the sensitivity of 228.6 pm/°C and 85.8 pm/°C, respectively. Based on the above result, a non-specific biosensor was demonstrated by an ink-jet printed Rhodamine 590 doped WGWM microdisk which successfully detected the BSA solution with a concentration of 100 ppm, and the thickness of adsorbed protein layer was calculated as 10~15 nm. This result provided the feasibility of a specific biosensor with the ink-jet printed WGWM microdisk.

Thirdly, the effects of gain intensity on spatial position of WGWM in an ink-jet printed QDs doped microdisk were experimentally and theoretically demonstrated. The spectral shift could be due to anomalous dispersion, dye degradation, and effects of gain intensity on spatial position. Initially, the influence of anomalous dispersion was eliminated by theoretical calculation. Then, QDs doped long-durability microcavities have been successfully developed to eliminate the interference of spectral shifts caused by dye degradation. Finally, it was successfully verified that the spatial position of WGWM moves inside of disk with increase in gain intensity based on the lasing spectra of ink-jet printed QDs microdisk, and it was also confirmed by numerical simulation based on Mark Oxborrow's model in COMSOL software. .

In conclusion, this thesis achievement is that for the first time the author discovered that the spatial position of WGWM(a special WGM in a microdisk with a sharp edge) is highly sensitive to external factors, and the mechanism has been analyzed and verified by experiment and simulation. This thesis clarified the knowledge for the spatial control of WGWM, it shows a feasibility that various applications with controllable mode spatial position or tunable physical properties can be realized by using optimized acute edge WGWM microcavities. It can be said that it shows important knowledge about future advanced application based on microdisk laser.