An Elctromagnetic Approach of The Photonic Quantum Ring

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The photonic quantum ring (PQR) laser shows the characteristics of an ideal quantum wire (QWR), like ultra-low threshold currents and $\sqrt{t}$ dependent spectral shift. For the PQR's toroidal cavity projected onto the active QW plane, the PQR region is defined by Rayleigh's bandwidth $\omega_{Rayleigh} = R(1-n_{eff}/n)$, where R is the active disk radius. The Rayleigh toroid associated with the PQR emission has helically twisted traveling waves[1,2]. The wave propagation phenomenon was analyzed using toroidal coordinate system associated with hypergeometric function[3]. The electromagnetic wave inside the torus is studied on the basis of Helmholtz wave equation

$$\nabla^2\pi_j + k^2\pi_j = 0 \quad (1)$$

By applying the conducting boundary conditions on the surface s=so, as $B_\sigma = 0$ at $s = s_\circ$ $E_\varphi(s = s_\circ) = 0$ $E_\psi(s = s_\circ) = 0$, the eigen frequencies are obtained from the following relation. $Kr_{s=s_\circ} = X_{mn}$ where $K = (2\pi/\lambda)n$, Xmn = first zero of hypergeometric function. In the PQR toroidal cavity, the helical propagation of the laser light is defined by bouncing of light wave between the DBRs and circulating wave due to total internal reflection .By using these two aspects, we can split the $\vec{K}$ into longitudinal and transverse components, which are defined by Fig. 1

$$K_z = K\cos\theta_{in} \quad K_t = K\sin\theta_{in}$$

The quantized emission wavelength of the PQR is given by

$$\lambda_{mn} = \lambda_\circ \frac{n_{mn}}{n_\circ}\left[1+\left(\frac{X^1_{mn}\eta_\circ}{2\pi R n_\circ}\right)^2\right]^{-1/2} \quad (2)$$

where nm is the effective refractive index (neff) for the mode with a wavelength λ mn.

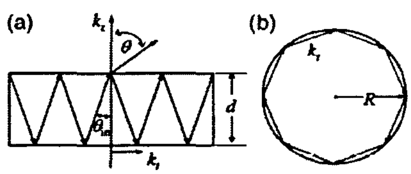
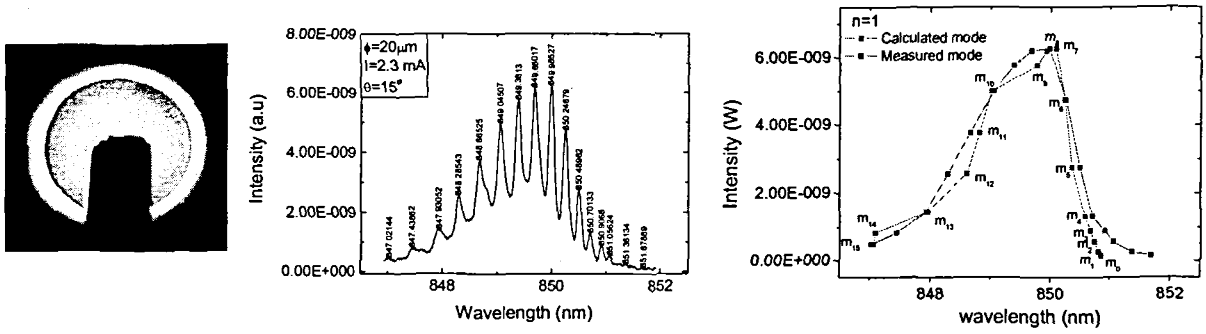


Fig. 1 (a) Side view of a bouncing light wave with an incident angle of ina toroidal 3D microcavity of thickness d, (b) top view of a circulating light wave with total internal reflection in a circular cavity of radius R.



(a) (b) (c)

Fig. 2 (a) CCD image of the PQR (b)spectra of the PQR of device size 20 m (c) comparison spectra of calculated and measured modes of the PQR of device size

Fig. 2(c) shows the comparison between calculated and experimentally observed modes of a 20 m laser for the case of n=1. By fixing the aspect ratio of the device and n=1 as constant and varying m value, we can obtain the X_m^1 for each mode using an algorithm developed in MATLAB. Substituting this value in the eqn. (2) we obtained the calculated mode spectra of the PQR. The simulated modes are in good alignment with the experimentally observed emission modes of the PQR at higher values of *n*. The calculated spectral modes of the PQR suggest that the hypergeometric functions are the appropriate functions to describe the normal modes of a toroidal cavity for the PQR.

References:

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