# High-Q Microdisk Resonator Having Sub-Wavelength Grating on Its Sidewall

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**Abstract**

**A novel type of dielectric microdisk resonator for integrated optics is proposed. The disk has angular grating on its sidewall, which exhibits guided-mode resonance (GMR) and thus functions as a highly reflective mirror for diverging waves inside the disk. Due to the wavelength sensitive property of GMR, a particular cavity mode can have large quality factor (Q) than other ones. Basic optical characteristics such as input/output characteristics, Q-factors, mode field patterns were investigated through Finite-Difference Time-Domain (FDTD) simulation.**

## I. Introduction

Recent progress in nano-photonics has enabled the creation of a number of light-handling functionalities on integrated optical circuits. Especially, high index contrast optics utilizing Si and related materials are of great importance for telecommunication and interconnection fields due to its compactness and CMOS-compatible production process [1-3].

Sensing is one of the emerging application fields for the above technology. Example functions are the efficient coupling between probe beam and light circuit, and the detection of a refractive index change. The use of resonant cavity structures having single and multiple ring geometries has been proven to be effective for these purposes [3,4]. Here, the control of quality factor (Q-factor), number of resonant modes and modal field profiles determine the device's feasibility.

In this paper, we propose a new class of microdisk cavities for integrated optics. The proposed cavity supports whispering gallery modes (WGMs) as conventional disk resonator. The difference is the angular grating structure which diffracts WGM to the center of the cavity. As explained in the following section, the cavity selectively excites a transverse mode with zero'th angular order number. Possible device function of the proposed resonator include, for example, high-Q cavity for refractive index sensors, laser cavity for Bessel beams, and grating coupler for vector beams [5].

## II. Structure and Principle of Operation

Fig. 1 shows a schematic view of the proposed resonator. Core layer (n=1.8, assuming SiN or SiON) is coated on $SiO_2$ substrate. Microdisk cavity (diameter=8.8μm) has 26 periods of semicircular gratings on its sidewall. Inside the disk an array of assist holes are also formed with the same angular period. The roles of these holes are to enhance diffraction and to limit the number of WGMs. The cavity is coupled to external circuits by bus waveguides. Recently we have demonstrated that curved grating, like the sidewall of the proposed structure, exhibited nearly 100% reflection owing to the guided mode resonance (GMR) for circularly diverging waves, just like conventional flat diffraction grating shows for plane wave [6]. It was also verified that cylindrical resonator surrounded by this curved resonant grating (CRG) supports extremely high-Q mode when resonance wavelengths of both cavity and CRG coincide [7].

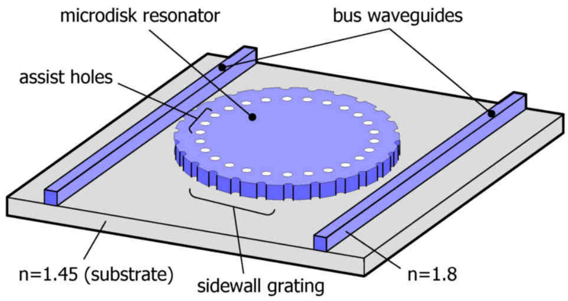


Fig. 1. Schematic view of the proposed microdisk resonator.

Basic operation of this resonator is as follows: signal light from bus waveguides excites WGMs. The modal power is gradually diffracted toward inside the disk, and again diffracted back to the WGM at the opposite side of the disk. This operation is common for TE (electric field parallel to the plane) and TM (magnetic field parallel to the plane) modes. However, throughout this study we focused on TM modes only, as the diffraction efficiency of TM is larger than the other. At GMR wavelength, diffraction angle becomes 90 degrees with respect to the tangential direction of the disk. This generates a converging concentric wave. This wave is in turn converted to diverging wave when it reaches to the center, and hits the CRG perpendicularly. Due to GMR this wave is reflected back toward center with ~100% reflectivity. As a result of that, radial standing wave pattern of the form of $J_0(kr)$ ($J_0$, $k$, and $r$ are the 0th order Bessel function, radial wavenumber, radial position, respectively) is formed and high-Q field confinement is attained. Hereafter we will call this "GMR mode".

Difference between the proposed CRG-microdisk and microgear resonator [8] is the relation between wavelength and the grating pitch. In microgear resonators the effective wavelength is about twice the pitch as it utilizes the lowest-order Bragg reflection. On the other

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hand, in the proposed structure the effective wavelength is nearly equal to the pitch for GMR to occur. WGMs immediately become leaky as the detuning from GMR wavelength increases.

## III. Result of Analysys

Input/output characteristics were calculated using Finite-Difference Time-Domain (FDTD) method. In order to obtain essential property of the cavity with limited computational resources, we utilized 2-D effective index approximation [9]. Approximated refractive index profile is shown in Fig. 2. TM mode is launched from the bus waveguide.

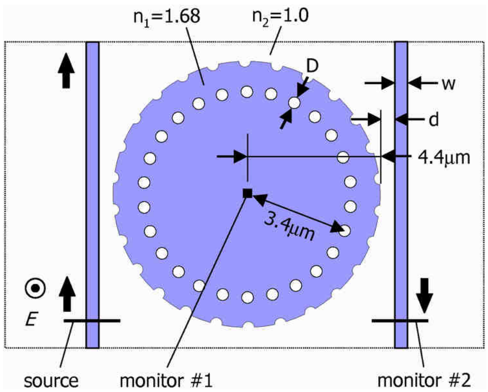


Fig. 2. Effective index profile of the calculated structure. Diameter of assist holes (D), waveguide width (w), waveguide-disk spacing (d), and the diameter of assist holes/semicircular sidewall gratings are all 0.4μm.

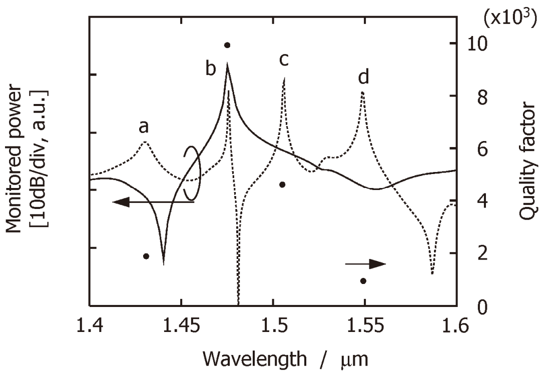


Fig. 3. Calculated power spectrum monitored at the center of the cavity (monitor #1, solid line), and at the drop port (monitor #2, dotted line). The solid circles denote quality factors of each resonance mode.

Fig. 3 shows calculated transmission spectra observed at the center (monitor #1 in Fig. 2) and at the drop port (monitor #2 in Fig. 2). The latter shows multiple longitudinal resonances as ordinary ring waveguide. The former implies that the mode at $\lambda$=1.475μm is distributed to the center of the disk, which is an evidence of GMR mode. In the figure Q-factors of each mode are also shown by solid circles. The Q of the GMR was about 9,900 and was about 2~10 times larger than adjacent ones.

Next, field profiles of each mode were calculated by launching CW waves from the waveguides. Results are shown in Fig. 4. Note that for this calculation all the waveguides ports were evenly excited in order to increase the visibility of each mode. GMR mode (b) represented clear concentric feature with large field intensity compared to that of bus waveguides. The other modes (a,c,d) showed radial field variation and weak confinement. This result verifies that this CRG-resonator operates as effectively single-moded in a wide wavelength range.

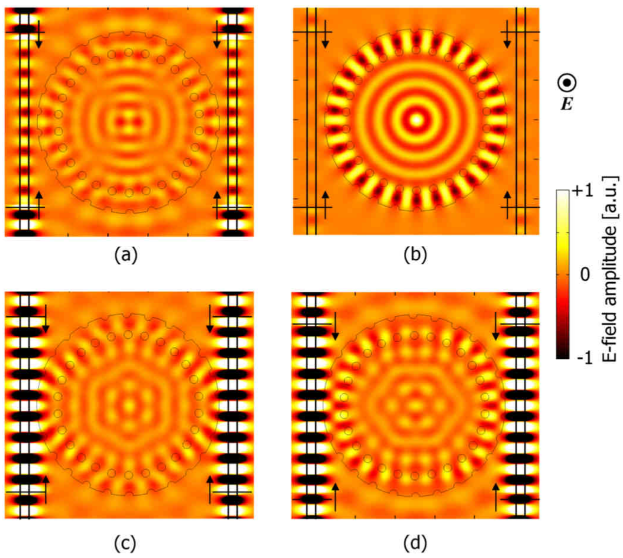


Fig. 4. Calculated electric field profiles of each resonance mode. (a), (c) and (d) correspond to the modes indicated by a ($\lambda$=1.431μm),c ($\lambda$=1.505μm), and d ($\lambda$=1.549μm) in Fig. 3. The mode (b) corresponds to the GMR mode at $\lambda$=1.475μm.

## IV. Conclusions

A grating-assisted microdisk resonator was proposed. Its optical characteristics such as input/output transmittance, field concentration inside the cavity region, Q-factor were analyzed using FDTD. The resonator was found to support high-Q circular mode which was confined by GMR of the grating wall. This resonator will be a useful component for creating and capturing Bessel-like beams from/to planar optical circuits.

## Acknowledgment

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