میکروتشدیدگرهای دیسکی

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چکیده – این نوشتار نوع جدیدی از آشکار ساز میکرودیسکی را ارائه می دهد که با بهره گیری از ضریب شکست تدریجی می تواند با حساسیت بیشتری نسبت به نوع ضریب شکست ثابت، آشکارسازی نماید. بررسی رفتار میکروتشدیدگر دیسکی با روش *FDTD* دو بعدی شبیه سازی شده است. جابجایی فرکانس تشدید برای لایه های با ضخامت های مختلف، برای میکرودیسک هایی با ضرایب شکست متفاوت مورد مطالعه قرار گرفته است. بهترین تابع ضریب شکست منجر به بیشترین میزان حساسیت و کمترین محدودیت آشکارسازی می شود. نتایج نشان می دهند، حساسیت آشکار ساز میکرودیسکی که ضریب شکست آن از تابعی مشخص با تقعر مثبت پیروی می کند، ۱۱ برابر بیشتر از نوع مشابه آن با ضریب شکست ثابت است.

کلید واژه- میکروتشدیدگر، آشکارساز، FDTD، حساسیت، GRIN.

The Role of Refractive Index Gradient on Sensitivity and Limit of Detection of Microdisk Sensors

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Abstract- This paper presents a new type of microdisk resonator sensor with a gradient refractive index (GRIN) that can achieve higher sensitivity with respect to constant refractive index disks. The behavior of the microdisk resonator is simulated by 2D-FDTD method. The shift in the resonance frequency for different thicknesses of the absorbed layer and different refractive index gradients of the microdisks are studied. The best refractive index gradient function is found that leads to the largest sensitivity and smallest limit of detection. The sensitivity of a GRIN microresonator sensor (GMS) with a convex quadratic refractive index function is approximately 11 times as much as that of homogeneous microdisk sensor, which is the best record among GMSs.

Keywords: Microresonator, Sensor, FDTD, Sensitivity, GRIN.

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1 Introduction

Microresonators have a wide range of applications such as microlasers, optical circuits, dynamic filters, and switches in optical communications [1,2]. Beside these, the use of microreonators as sensors represents a further extension of the optical microcavity applications[3].
A microresonator coupling system is sketched in Fig.1.

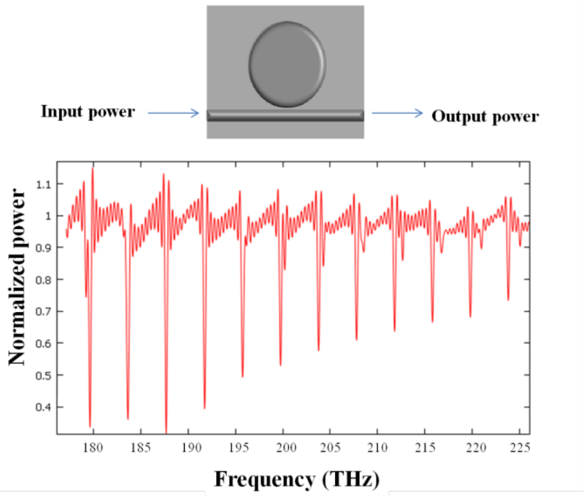

Figure1. Illustration of a microdisk resonator coupled to a straight waveguide. Normalized power is derived from division of output to input power spectra.

Graded refractive index (GRIN) structures are inhomogeneous media with spatially varying refractive index distributions. They are widely used in photonics applications due to their unique light coupling, focusing and switching abilities [4].
In the present paper, we propose GRIN microresonator sensors (GMS). It will be shown that GRIN structure leads to major improvements in the sensor operation of photonic microresonators. We study the sensor application of GRIN microresonators using FDTD simulations. We then compare the sensitivity of some microdisks with different radial refractive index functions and examine different types of refractive index gradients to find the best function that leads to more sensitivity and less detection limit.

2 Sensor Considerations

To study sensing application of microdisk resonators, we should consider some common sensor parameters. Sensors are often quantitatively compared in terms of their sensitivity. Here, we define sensitivity as the magnitude in the shift of the resonant wavelength (λ_r) or the resonance frequency (υ_r) versus the change in thickness (t) of the absorbed layer in the case of surface sensing [5]:

$$S = \frac{\partial \lambda_r}{\partial t} = \left| \frac{c}{\upsilon_r^{\,2}} \frac{\partial \upsilon_r}{\partial t} \right| \qquad (1)$$

However, this measure alone is not sufficient for characterizing the ability of a sensor.

To fully describe the performance of the sensor, the detection limit must also be considered. The detection limit is defined as $\delta\lambda_r$/S, where $\delta\lambda_r$ is the minimum distinguishable wavelength shift and S is the sensitivity. Experimentally, $\delta\lambda_r$ can be taken as a fraction of the band-width of the resonance, which is defined as the full width at half maximum (FWHM) of the resonance. The sharper the resonance, the smaller $\delta\lambda_r$ can be achieved. Hence, the detection limit is proportional to FWHM/S or 1/ (Q · S), where Q is the quality factor of a resonance. To evaluate the performance of a sensor, we use the detection factor P = FWHM/S [5]. The detection factor is a measure of the detection limit of the sensor. In the design of a sensor, a small detection factor is desirable.

3 FDTD simulation results

Here we use the finite-different-time-domain (FDTD) method which is an explicit grid-based technique for the dirrect solution of the fundamental Maxwell curl equations [6]. Figure 2 shows a typical geometry of a microdisk-waveguide coupling system.The simulation domain is an 8μm×8μm rectangular area with a centered 5μm-diameter microdisk with a gap of 0.231 μm between the disk and a straight 0.3-μm-wide waveguide. n_d is the refractive index of the disk, and n_f is the refractive index of the fiber that is equal to 3.2.

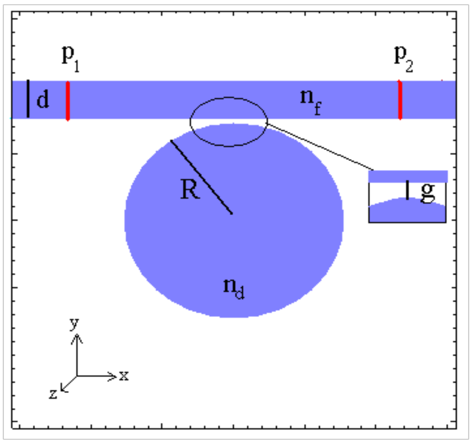

Figure2. Typical geometry of microdisk simulation domain.

The excitation source is a 20-fs Gaussian pulse modulating a 200-THz carrier. The field components in the pulsed waveguide mode are recorded as it propagates past cross sections p_1 and p_2.

To calculate power spectra, at first, the discrete Fourier transform of the time histories of the electric and magnetic fields is computed at each grid point along p_1 and p_2. Next, using $S = {}^1/_2\, E \times H^*$, the total longitudinal power flux passing through the waveguide at all the grid points of cross-sections at each frequency is calculated. Finally, by averaging over obtained values and dividing transmittance to incoming power flux average, we would have normalized power spectra versus frequency.

It is of interest to see the effect of the refractive index function of the microdisk or the slope of the graded index on the sensing capability of the microdisk. Some interesting types of microdisks are shown in figure3.

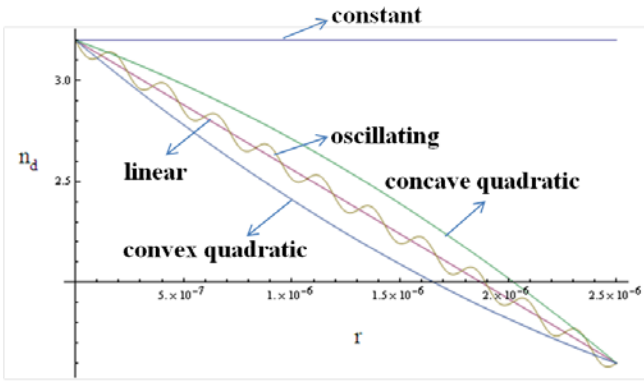

Figure3. Some interesting types of microdisk with gradient refractive index functions.

Each type of microdisks has a different output power spectrum.

To study the sensing behavior of each microdisk, we check the output power spectrum for different surface layer thicknesses. By increasing the layer thickness, the spectrum shifts to lower frequencies due to the larger effective optical path on the periphery of the disk. Figure 4 shows these shifts for the linear microdisk sensor.

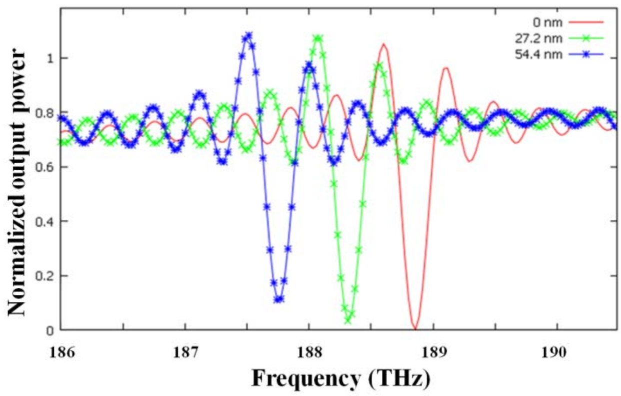

Figure4. Resonance frequency shift for the convex quadratic sensor.

By determining the shift of a certain resonance frequency(Δν), for different layer thicknesses (t), the sensitivity S is obtained. The curves in figure 5 indicate different slops or sensitivities for different types of microdisk sensors. It shows that a microdisk sensor with convex quadratic refractive index function has the highest sensitivity which is approximately eleven times higher than that of a constant microdisk sensor.

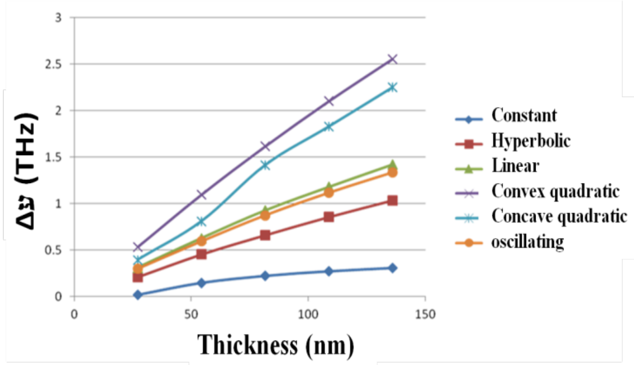

Figure5. frequency shift versus layer thikness for different types of microdisks.

Now, by using equation (1), the sensitivity of microdisk sensors is extracted. The next step is to calculate parameter P (which was defined in section 2) that is a measure of the detection limit of the sensor. Table 1 displays the results.

Table2. Sensitivity, FWHM and P parameter (i.e. measure of detection limit) for different types of microdisks.

Sensor type	S	FWHM(THz)	P(THz)
Constant	2.526	0.194	0.0768
Linear	16.190	0.186	0.0114
Oscillating	15.079	0.175	0.0116
Second order with positive concavity	29.680	0.237	0.0079
Second order with negative concavity	27.619	0.358	0.0129

A microdisk sensor with radial concave quadratic refractive index gradient has the least limit of detection and highest sensitivity among other microdisks listed in the table. Although, the least FWHM belongs to the oscillating type, the effect of sensitivity leads to a higher detection limit for this microresonator.

It is clear that extending the domain of the simulation or shape of microcavity may increase the computational quality factor or sensitivity. But our goal is merely to study the refractive index gradient effect on the sensitivity and limit of the detection of a simple microdisk sensor.

4 Conclusion

We have described GRIN microdisk sensors (GMS). The shift of the resonance frequency for increasing layer thickness on the surface of the sensor was investigated for a special resonance frequency by exploiting 2D-FDTD. It was shown that GMSs can achieve more sensitivity and limit of detection than homogeneous microdisks. Also, the results indicate that a radial convex quadratic refractive index function for microdisk sensors is the best choice. It demostrates 11 times enhancement in the sensitivity and 6 times enhancement in the limit of detection of the GMS.

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