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Whispering Gallery Mode Resonator at Terahertz Frequency domain: A Brief Review

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ABSTRACT: Whispering Gallery Mode Resonators represent a class of cavity devices with exceptional properties such as extremely small mode volume, very high power density, and very narrow spectral line width. Their importance for applications in very sensitive micro-sensors, have been recognized only in recent years. The sensitivity of this resonant technique has been found to be single molecular level, higher than that compared to most optical single pass devices such as Surface Plasmon Polariton. In this paper we present a brief review of the field of WGM resonators, which includes the basic concept, the geometrical structures of resonators, different materials and methods.

KEYWORDS: WGMR, dielectric, THz, Optical resonators

I. INTRODUCTION

Whispering gallery modes or waves are specific resonances modes of a wave field (e.g. sound waves, electromagnetic waves) inside a given resonator (a cavity) with smooth edges. They correspond to waves circling around the cavity, supported by continuous total internal reflection off the cavity surface, that meet the resonance condition.After one roundtrip they return to the same point with the same phase (modulo) andhence interfere constructively with themselves, forming standing waves). These resonances depend greatly on the geometry of the resonator cavity.The report on recent study of resonators made out of sapphire, diamond, and quartz crystals and discuss possible applications of these resonators. Here we discuss resultsconcerning fabrication of high-Q sapphire, diamond, and crystal quartz whispering gallery mode resonators, and demonstrated the highest reported Q-factor in a monolithic resonators fabricated out of the materials[1].The resonators can be useful in a variety of scientific and technical applications, includingfabrication of ultra-stable optical etalons, cavity stabilized lasers, and opto-electronic radio frequency oscillators. The electromagnetic and radiation fields are obtained by solving the time domain Maxwell's equations using the finite element analysis [5]. It is found that the increase of either effective microsphere size or the refractive index of the medium surrounding the microsphere down-shifts the WGM resonance frequency. The larger the change, the stronger is the shift. A linearrelationship between the variation of microsphere effective size and the resonance frequency shift is found.

This characteristic may be used for the monitoring of peptide growth in the solid phase synthesis. The glass based sphericalmicro resonators area easy to study and apply important physical effects [6]. Here they discuss about high sensitivity detection of disease marker in point of care testing, high throughput screening of lead compounds in drug discovery as well as basic research studies in various disciplines within the life sciences such as signal transduction, protein folding and membranebiophysics[7]. Demonstrated the feasibility to fabricate quartz and polyethylene whisperinggallery mode resonators for the THz frequency range with coinciding mode spectra overmore than ten times the free spectral range[8].Point out the advantage of large size and the possibility of post processing ofWGMresonators in the Terahertz frequency range. This allows for designing, manufacturing and examining photonic molecules. Have been demonstrated this by fabricating two cavities with matched resonance spectra and coupling them to photonic molecules. The achieved mode splitting is in fine agreement with theoretical calculations. WGM is among the most sensitivity and accurate technique proposed to date for sensing and dielectric characterization[9]. The technique to measure strain using WGM sensors is analyzed by developing a theoretical framework. A combination of analytical and Finite Element Analysis (FEA) method is used to calculate the strain and change in the index of refraction of the microspherematerial, which are combined to obtain the shift in WGM[10].

II. BASIC CONCEPT

Resonant phenomena in cavities of acoustic and optical domains frequently depend on the geometric properties such as size and shape, and also on the composition of the cavities. Such resonances are often known as Morphology Dependent Resonances (MDRs). An important example of MDR is that of whispering gallery mode resonator in the acoustic domain. As mentioned in the introduction, the WGM in the acoustic domain comprises a moving pressure wave guided around a closed concave surface, like the whispering gallery in St. Paul's Cathedral shown in a schematic Figure 1(a).From geometric considerations, neglecting absorption, scattering, and material dispersion, these modes are guided by repeated total internal reflections and continue endlessly. However, in reality, the wave losses continue through the surface via absorption, scattering, and material dispersion, and mode undergoes a decay in its amplitude, in the absence of an external excitation, thereby causing a finite lifetime. It is important to note that WGM is a subclass of MDR and is characterized by its surface mode nature and high quality (Q) factor as a result of low losses.

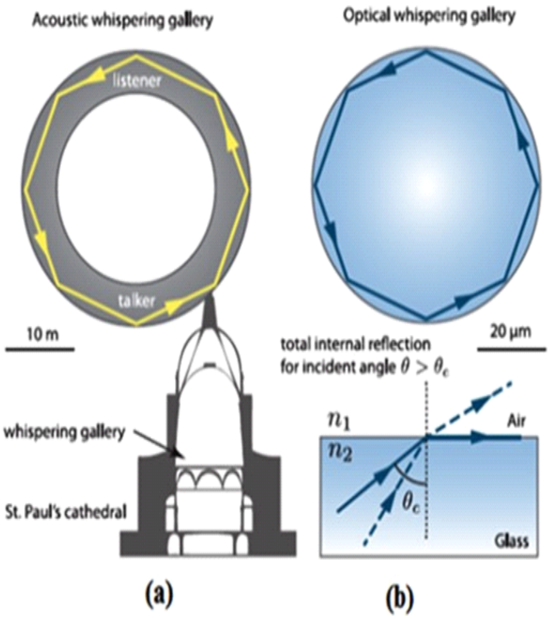

Fig 1: WGMs supported by total internal reflection in (a) an acoustic mode, and (b) an optical wave.

Figure 1(b) shows the schematic of WGM in the optical domain illustrating WGMs can also occur in optical cavities having a closed concave interface. Among the important and simplest WGM geometries in the optical domain are discs/cylinders, spheres, and ring cavities which have been studied extensively during the last two decades. Since the resonators in the optical domain are in the region of few 10's of micrometers, they are generally difficult to fabricate and also tune to the optical waveguide, though they give rise to extremely high Q factor. On the other hand, THz waves have an advantage, since the WGMRs in the THz domain are in the sub-millimeter and millimeter range which are easy to fabricate and also to tune to the THz waveguide. Hence, substantial work is going on currently on WGMRs in the THz domain.

III. THE Q-FACTOR OF WGMR DEPENDS ON FOUR CONTRIBUTING FACTORS AS FOLLOWS

Quality factor due to decay caused by the fact that, unlike a flat surface, the total internal reflection from a curved surface leads to a radiation of thewave from the dielectric sphere. Such decay can be called as radiative decay. Corresponding to this phenomenon we define a radiative quality factor.Quality factor due to surface scattering losses due to residual surface irregularities.vQuality factor due to surface contamination. Quality factor due to material property of the resonator, this is related to the contribution due to absorption of light and bulk rayleigh scattering in the material of the micro resonator.

IV. LITERATURE SURVEY

Types of materials used for observations

A. Sapphire

Sapphire has high enough index of refraction and is easily machinable, it is well suited for planar integration. Mid-IR transparency of the material makes it promising for generation of frequency combs in this spectral region.

B. Diamond

Diamond has an extremely broad optical transparency window, there is little consistent experimental data on its attenuation within the window.The diamond that had approximately 20 ppb of nitrogen impurities in the solid, which results in extremely low levels of absorption across the whole transparency spectrum. This kind of a diamond was utilize to build the WGM resonator. Diamond parts for quantum computing applications have been produced in thin layers with nitrogen impurities below 1 ppb, and it can be foreseen that using the techniques exploited in the synthesis of these layers that in the future evenlower absorption bulk diamond can be produced.

C. Quartz

Glass is a non-crystalline, amorphous solid that is often transparent. The most familiar, and historically the oldest, types of manufactured glass are "silicate glasses" based on the chemical compound silicathe primary constituent of sand. Glass will transmit, reflect and refract light. Glass can be coloured by adding metallic salts, and can also be painted and printed. The varieties of glass differ widely in chemical composition and in physical qualities. Glasses of very different, and often much more expensive, compositions are made when special physical and chemical properties are necessary.

DIFFERENT SHAPES OF WHISPERING GALLERY MODE RESONATOR (WGMR)

A. CYLINDRICAL

WGMRs have the simplest geometry and are easy to fabricate.The simplest cylindrical WGMR, however, is constituted by a small piece of aconventional telecom single-mode optical fiber (chosen due to its high material quality), stripped from coating and suitably cleaned. In such a structure, a ray radiates along the tangent from the radiation caustic where the core mode loses its confinement and then is subject to total internal reflection at the boundary between the cladding and the air.

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B. SPHERICAL

Micro spherical resonators are extremely simple to fabricate, can reach extremely high Q factors and were the first WGMRs tested as biosensors. A micro spherical resonators is constituted by spherical dielectric structures, where optical rays are total internal reflected. Due to minimal reflection losses and potentially very low material absorption, they provide high quality factor Q, leading to high energy density.

C. MICRORING AND MICRODISC

Microring and microdisc resonators have lower Q factors than other WGMRs, but can be easily fabricated. Depending on their size and the degree of deformation, these micro resonators can support several types of optical modes with significantly different Q-factors, near-field intensity distributions, and emission patterns.

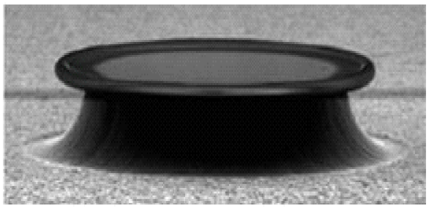

Fig 2: Image of microdisc

V. MEASUREMENT METHOD

Primarily two types of measurement techniques can be used to accurately measure high Q-factor of WGM resonators based on the analysis of the intensity transmission transient profile namely, stationary approach and dynamical approach[3].

Stationary approach: The most common method used to measure the Q-factors of high and ultra-high-quality WGM microresonators involves linearly scattering of the frequency of a narrow probe laser at the input of the resonator and to simultaneously record its transmission. The frequency of the laser is linearly swept while keeping the amplitude |sin(t)| constant. The source is modeled by as a monochromatic signal whose instantaneous frequency is written as $v(t) = v_i + v_s(t)$,where v_i is the initial frequency and v_s is the frequency sweeping rate. The laser probe is attenuated only when it is tuned to the resonator frequency v_0(resonant frequency.

Dynamical approach: The Stationary approach is valid only for very low sweeping rates, $v_s << v_{so,}$ which is necessary to record the stationary response of the resonator v_{so} is the scanning rate corresponding to bandwidth of the resonator. For higher frequency sweeping rates, the excitation cannot be considered as stationary and a ringing phenomenon strongly modifies the profile of the transmission spectrum due to the beating of the input and the intracavityfields.

VI. APPLICATION

- Use of photonic filters based on optical whispering gallery resonators is among the most developed applications of whispering gallery resonators. The intent is to use them for processing signals in optical communications, where ring resonators with Q-factors are adequate.
- Biosensing and other sensing applications, such as detection of analytes down to a single molecule, measuring changes in pressure, temperature by measuring changes in the Q-factor and resonant frequencies.
- The application of whispering gallery mode resonator are used very sensitive sensors which can be affected by things such as the pressure, temperature and chemical composition of their surroundings.

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VII. CONCLUSION

Whispering gallery mode (WGM) resonators offers a applications due to their extremely high quality Q-factor. WGM biosensor can distinguish molecular size change in the magnitude of ~10^{-4} nm and refractive index change in the magnitude of ~10^{-6}. WGM spherical resonators can be extended to high sensitivity detection of disease markers in point of case testing and high throughput drug screening. Due to extraordinary low absorption and scattering losses, WGM resonators can have ultra-small line widths down to the kilohertz range. Because of the large size, terahertz WGM resonators are easy to handle and also their fundamental modes are accessible. WGMs can be described as propagating modes around the centre of Dielectric Resonator(DR) with repeated total reflection from the rim of the resonator and phase shift of integer multiples of 2π in each rotation.

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