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WHISPERING GALLERY MODE DIELECTRIC RESONATORS FOR THE MILLIMETER WAVE NEAR FIELD SENSING APLLICATIONS

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ABSRACT

The resonance characteristics of whispering gallery modes (WGM's) in parallel-plates type cylindrical dielectric resonators (DR's) are numerically considered to optimise their characteristics for sensing applications. Results for the dependency of the resonant frequency, Q-factor, slow-down factor and electric energy filling factor of the modes on resonator parameters for both isotropic and anisotropic DR are presented. The possible applications of the results for millimeter wave near field non-destructive measurements are discussed.

INTRODUCTION

Dielectric resonators (DR's) with whispering gallery modes (WGM's) and devices with them have been under investigation for several years and they have been especially intensively studied lately [1-3]. The reason is the certain advantages of WGM DR's in microwave and millimeter wave region, such as high Q-factor, field localisation in the narrow area near the dielectric boundary. The open nature of these resonators leads to their sensitivity to the external medium and elements and this property together with high Q-factor is very attractive for sensing applications.

Cylindrical DR's with WGM's are promising structures for applications. The design of such resonators requires the accurate computation of the resonant frequency and Q-factor of the operating mode, and determination the influence of the anisotropy property on the resonant modes. Krupka *et al.* [1] rigorously analysed the WGM's in shielded anisotropic dielectric resonators. They presented some numerical results on the resonant frequencies and the Q-factors of such resonator. Kobayashi *et al.* [4] obtained the characteristic equation and mode charts for low order modes in parallel-plates type cylindrical anisotropic resonator. In a more recent study [5], the analytical expressions for partial Q-factors were received for such resonator.

At present, it is necessary to numerically investigate the WGM's in different types of parallel-plates type cylindrical resonators for optimising their performances. In this paper, the dependency of resonant frequency, Q-factor, slow-down factor and electric energy field filling factor of WGM's on resonator parameters is studied numerically by using the developed computer programs. Resonators with different materials and dimensions are investigated. Finally, applications of the results for sensing purposes are discussed.

DR MODEL

Fig. 1 shows the resonator structure that is a parallel-plates-type resonator, where a dielectric cylinder is placed between two parallel, infinitely large conducting plates. The dielectric cylinder is assumed to have homogeneous uniaxial-anisotropic characteristic with the c-axis of the dielectric parallel to the z-axis. The permittivity parallel and perpendicular to the c-axis is defined as ε_z and ε_r, respectively. Thus $\varepsilon_\phi = \varepsilon_r$ and we assume no off diagonal terms in the permittivity tensor. The relative permittivity of the dielectric is assumed to be $\mu_r = 1$, and the conductor is also assumed to be lossless.

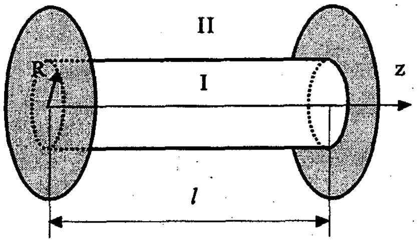

Fig.1. Parallel-plates type dielectric resonator

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RESULTS

Numerical results are presented for $m = 0$ where the parallel-plates-type dielectric resonator can support only TM mode. We firstly considered the isotropic DR made from quartz ($\varepsilon = 3.78$, $tan\ \delta = 1x10^{-4}$). In Fig. 2, the horizontal axis gives the ratio of resonator radius, R, to wavelength, λ, whereas the vertical axis shows the normalised slow down factor, (U – 1). Information is given for two radial modes ($s = 1,2$).

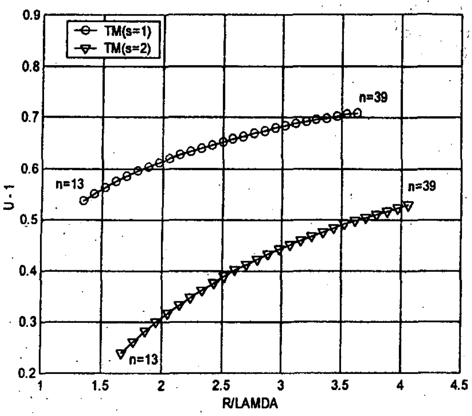

Fig. 2. Normalised slow down factor vs. R/λ.

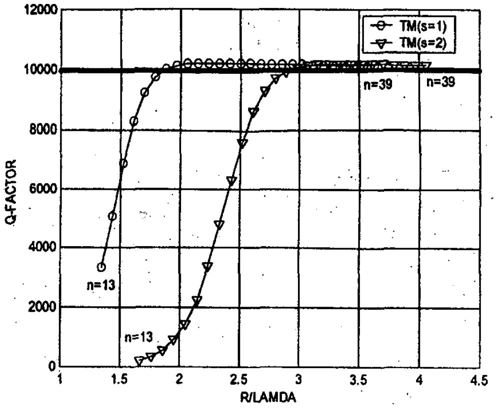

Fig. 3. Q-Factor vs. R/λ.

It can be seen from Fig.2 that slow down factors of the lower order radial ($s = 1$) modes are greater than that of the higher order radial ones ($s = 2$). This means that the fields of the latter extend further in the outer medium. In Fig. 3 we show the dependencies of the Q-factor of the investigated modes on the parameter R/λ. The bold solid line gives a level of dielectric losses tangent, $(tan\ \delta)^{-1}$. As is seen from Fig. 3, the lower order radial mode has higher Q-factors than the higher order radial one for $R/\lambda < 3$. This is a result of their different radiation losses. For $R/\lambda > 2$, the dependency of the lower order radial mode Q-factor to (R/λ) has a non-monotonous character and the values of Q-factor are greater than the $(tan\ \delta)^{-1} = 1x10^{4}$ level because of the localisation of some field outside the resonator. The same behaviour for the Q-factor of the higher order radial mode is observed when $R/\lambda > 3$.

Secondly, we considered the characteristics of the modes of the anisotropic resonator. In Fig. 4 we show the spectra of TM_{n0s} modes of the resonator ($\varepsilon_t = 4.66$, $\varepsilon_z = 4.41$) in the same manner as in Fig. 2. It can be seen from Fig. 4 that slow down factor of the TM mode with $s = 1$ is greater than that of TM with $s = 2$. Fig. 5 shows the dependencies of the Q-factor of the investigated anisotropic DR modes on the parameter R/λ. Comparing with Fig. 3, we see that the level of the Q curves become comparable for $R/\lambda > 3$, meaning that only dielectric losses are present in the specified region for both modes of different type DRs.

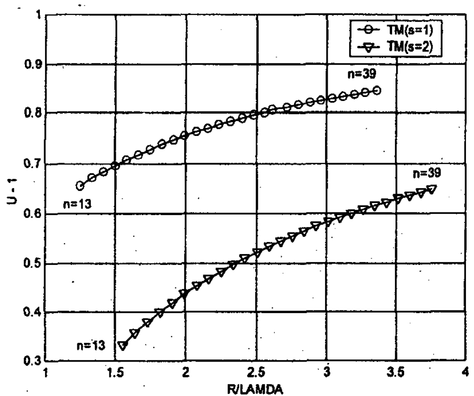

Fig. 4. Normalised slow down factor vs. R/λ.

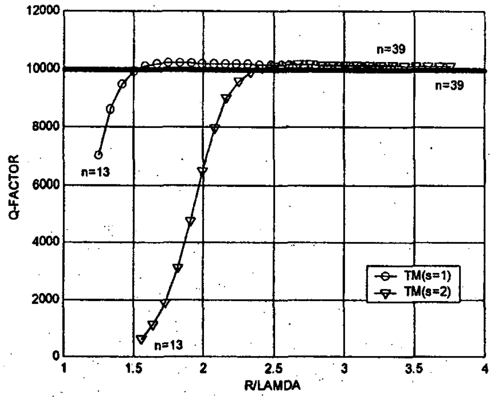

Fig. 5. Q-Factor vs. R/λ.

Fig. 6 shows the dependencies of the electric energy filling factors, γ, of the investigated lower order radial modes on the parameter R/λ for isotropic and anisotropic DR. We can see that the electric energy filling factor of the anisotropic DR is greater than that of the isotropic DR because $\varepsilon_z > \varepsilon$. The filling factor increases with the increase of R/λ for both DR's.

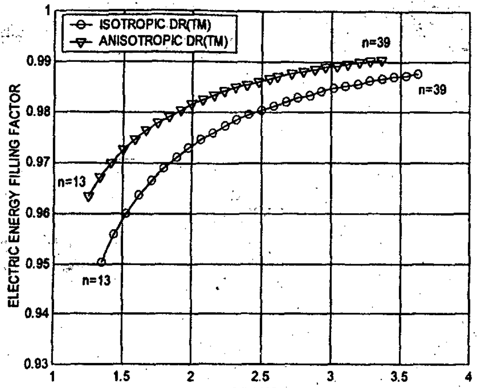

Fig. 6. Electric energy filling factor vs. R/λ.

DISCUSSION ON POSSIBLE APPLICATIONS

It's possible to use the obtained results for the optimisation of the investigated resonator characteristics for specific applications. For instance, for sensing purposes, the DR has to be designed to assure a high sensitivity, that is, the resonator response has to be as high as possible for changes in the electromagnetic properties of the outer medium. This sensitivity depends on the strength and distribution of the evanescent field in the outer medium [2]. It is proportional to the ratio of the power of the WGM at the outer medium to the total power of the WGM, that is, to electric filling factor of the evanescent field ($\gamma' = 1-\gamma$). We have shown how sensitivity can be increased by selecting the frequencies, dielectric properties and size of the resonator. To obtain a high sensitivity we must decrease the electric energy filling factor. This factor decreases with a decrease of the dielectric permittivity and the radius of the resonator. It gives us more clear spectra, too. However, we are limited with the decrease of Q-factor because of radiation losses. Thus, it's necessary to use a compromise between the Q-factor and filling factors.

CONCLUSION

The cylindrical DR with WGM's is a promising structure for applications. Numerical results for the resonance frequency, Q-factor, slow-down factor and the electric energy filling factor of a parallel-plates-type cylindrical DR with WGM's are presented. The obtained results proved the possibility of optimisation of the resonator characteristics for specific applications, namely for sensing applications.

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