2023 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC) | 979-8-3503-4599-5/23/$31.00 ©2023 IEEE | DOI: 10.1109/CLEO/EUROPE-EQEC57999.2023.10232112

# Ultra-sensitive micro-toroid resonator sensor capable of resolving the angular orientation of nanoscale objects

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Optical micro-resonators, capable of sustaining whispering gallery modes, are proven ultra-sensitive sensors with sensing limits up to single virus detection, where the sensing limit is dependent on the resonator's quality factor, mode volume as well as the electric field intensity at the sensing location [1-2]. Improving the sensing limit of such sensors will provide a platform that along showing ultra-sensitivity can have specificity, making such sensors feasible candidates for fundamental life studies such as studying the dynamic of a single DNA strand. A promising approach in this regard is coupling the plasmonic excitation of a nanoparticle to the whispering gallery mode within the micro-resonator, which enhances the electric field intensity at the sensing location and subsequently improves the sensing limit. However, a drawback of such techniques is the confinement of the sensing area to the nanoparticle's close vicinity [3].

In the present work, adding a silver nanoring along the micro-toroid's equator is proposed, which has the advantage of providing a larger sensing area and thus an extended platform compared to only a single nanoparticle. It should be mentioned that such metallic ring will reduce the quality factor of the micro-toroid by orders of magnitude, however, through designing the nano ring in a way that spectral position of the plasmonic excitation is located near the micro-toroid's resonance wavelength, a significant electric field enhancement is achievable resulting in an overall improved sensing limit. A silica micro-toroid (in air) with 8µm major and 1.5µm minor radius is simulated using COMSOL Multiphysics, where the resonance wavelength of the 93rd azimuthal mode occurs at 848.6nm [4]. A silver nanoring with 30nm thickness is added to the equator of the micro-toroid. It is shown that through coupling the photonic mode of the micro-toroid to the plasmonic mode within the ring, the electric field at the equator increases up to four times and since the sensing limit is proportional to the square of the electric field strength, a major enhancement in the sensing limit is expected.

To determine the sensing limit, a dielectric 2.4nm ellipsoid having the typical size of a DNA strand is positioned at the equator in presence and absence of the silver nanoring, while analysing the resonance wavelength shift as the sensing limit's figure of merit. Our simulations show that in the absence of the ring, the wavelength shift is less than 1fm, while through adding the nanoring, the resonant wavelength shift is about 23 times larger. Such improved sensitivity can be used to resolve the ellipsoid's respective the DNA strand's direction with respect to the micro-toroid's surface, due to a change in the ellipsoid's polarization, where normal, 45° tilted and horizontal directions are detectable, as the 6.7fm wavelength shift in case of the perpendicular ellipsoid (the angle is defined as the angle between the ellipsoid's major axis and the toroid's major axis ) changes to 4.8fm wavelength shift for the case of 45° tilted ellipsoid and to 3.9fm for the horizontal ellipsoid.

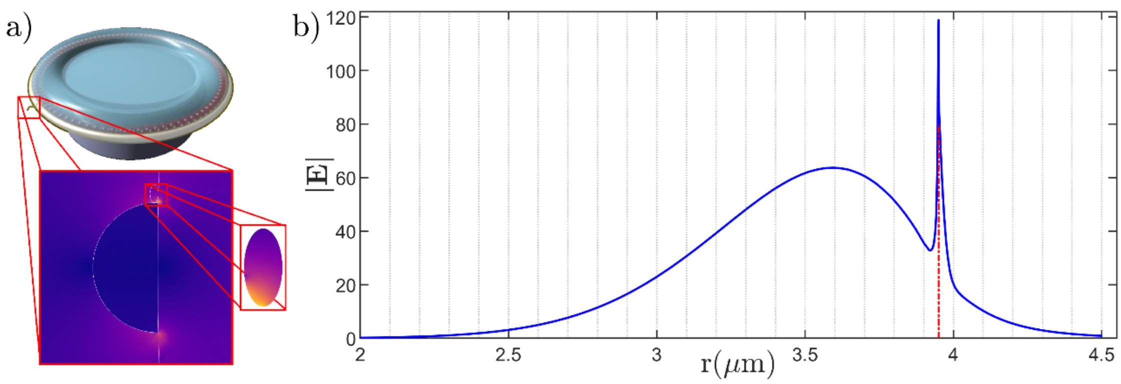


**Fig. 1** a) The schematic of the micro-toroid with the silver nanoring, where the electric field distribution around the silver ring and inside the ellipsoid are shown. b) The electric field along the toroid major axes, where the red dotted line depicts the toroid surface. The peak is due to the enhanced electric field around the nanoring.

## Example References

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