FROM SENSING TO MAKING SENSE

Microtoroid Optical Chemosensors Augmented With Nanostructures For Mechanically Robust And Stable Sensing

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Background: Microtoroid resonators are one of the most sensitive sensing technologies due to their ultra-high quality factors Q > 10^7. These sensors exhibit a resonance for a particular wavelength of light, which shifts when an analyte comes into contact. The amount of resonance shift scales with analyte concentration, so sensitivity to low concentrations requires the detection of very small shifts. Resonances with narrow linewidths can be tracked with greater precision than broad resonances. The Q, which is equal to the resonance wavelength divided by its width, provides a metric for the smallest resonance shift that can be tracked.

Purpose: While microtoroid resonators have extremely low limits of detection, coupling light into them typically requires expensive and bulky equipment such as vibration-isolation tables and piezoelectric nanopositioning stages. Translating microtoroids to autonomous and deployable platforms with small size, weight, power, and cost (SWAP-C) remains a challenge.

Objective: We aim to fabricate photonic nanostructures on the surface of microtoroids in order to facilitate free-space coupling via inexpensive and imprecise optics without significantly degrading the microtoroid quality factor or efficiency. This approach would enable the translation of these highly sensitive sensors to widely deployable, low SWAP-C platforms.

Rationale: Photonic nanostructures that are fixed to the microtoroid surface provide an optical coupling channel that will be robust to mechanical vibrations and disturbances.
Relationship to other areas of study: Although primarily focused on chemical vapor sensing, our work can be related to biosensing.
Methods: We have designed the nanophotonic coupler using numerical finite element simulations with novel boundary conditions to accommodate a large simulation domain relative to the optical wavelength and nanostructure size. The nanophotonic coupler is assembled using a custom manufacturing platform based on automated optical tweezers to attach nanostructures to the sides of microtoroids in precise locations. This unique approach enables 3D photonic microscale devices to be augmented with nanoparticles of different materials.

Preliminary results: In simulation, we can visualize the flow of light into and out of the nanostructure-augmented microtoroids and determine their spectral response. Experimentally, using optical tweezers, we can manipulate nanoparticles faster than 0.35 mm/s, which is the fastest nanoparticle manipulation speed recorded to date and is key for high throughput assembly of these multiscale structures. We also demonstrate the ability to attach particles with nanoscale precision, either evenly distributed along the equator of the microtoroid resonator, or at precise latitudes for coupling to higher order optical modes. We have experimentally confirmed free-space coupling into and out of microtoroids via these nanoparticle arrays.

Preliminary conclusions: Photonic nanostructures that are precisely positioned in 3D using optical tweezers provide a robust method of coupling light into and out from microtoroid sensors.
Impact to the DTRA mission and warfighter: We aim for these sensors to be autonomous, robust, multiplexed, and low SWAP-C for widespread deployment.

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