Optical Microcavities: From sensing single molecules with WGM microlasers to applications in synthetic biology

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We report the use of whispering-gallery mode microlasers for single molecule sensing, leveraging their exceptional label-free sensing capabilities. Specifically, we focus on silica microspheres doped with rare earth ions, particularly Yb^{3+}, due to their favorable characteristics for sensing applications. Our investigation reveals that microlasers exhibit enhanced sensitivity for detecting single biomolecules, viruses, and gas molecules.

In our study, we demonstrate the effectiveness of microlasers in detecting single molecules through spectral shift techniques, exploiting the Purcell effect to achieve remarkable sensitivity levels. By utilizing a heterodyne technique with plasmonic gold nanorods (NRs), we enhance sensitivity further, enabling the detection of individual biomolecules with unprecedented accuracy.

Our findings underscore the potential of microlasers as a powerful tool for single molecule sensing, offering insights into molecular binding dynamics and conformational transitions. This research opens up new avenues for applications in diverse fields, ranging from biomedical diagnostics to environmental monitoring.

Building upon the sensitivity and time resolution achieved by optoplasmonic WGM sensors, which enable the detection of sub-nanometer conformational changes and measurement of single enzyme free-energy penalties, we propose employing these sensors to explore strategies for controlling enzymatic processes at the single-enzyme level. By harnessing the high sensitivity and micro/nano-second time resolution of optoplasmonic WGM sensors, researchers can achieve real-time control over enzymatic synthesis. Various methods, including temperature control, plasmonic heating, and optical forces, can be integrated with the sensor platform to regulate enzyme activity and precisely control the chemical environment.

Overall, the unique capabilities of optoplasmonic WGM sensors provide synthetic biologists with a powerful tool to investigate, design, and precisely control biological systems at the single molecule level, offering potential breakthroughs in bio-manufacturing, DNA synthesis, and membrane protein studies.

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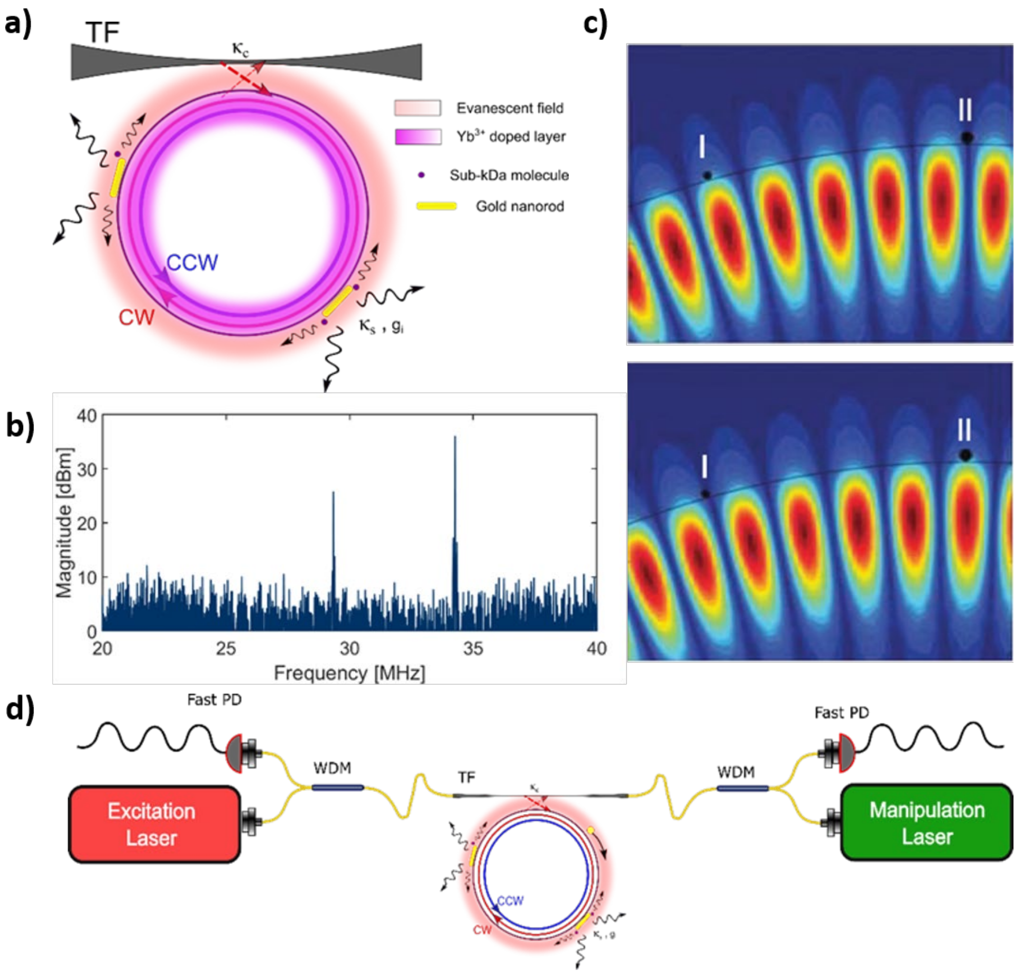

Figure 1: *<u>Optoplasmonic WGM microlaser for single molecule sensing</u> (a) An optoplasmonic WGM microlaser excited by an excitation laser beam through a tapered fiber. The initial excitation is in the CW direction. However, by introducing plasmonic gold nanoparticles, which act as nanoantennas for single molecule detection, SWMs form with non-degenerate eigenfrequencies. This mode splitting between CW and CCW WGMs is reflected as a beatnote in the lasing output. Small molecules interacting with the gold NRs alter the splitting frequency of the SWMs. (b) An example of microlaser beatnotes at approximately 30 and 35MHz. Two beatnotes represent two independent lasing modes taking place in the microresonator. (c) The field distributions of SWM1 and SWM2 when multiple gold NPs are attached to the microcavity. (d) The schematic of the optical setup required. Adaped from:* https://doi.org/10.1021/acsphotonics.3c01570