Measuring the Charge of a Single Dielectric Nanoparticle Using
a High-Q Optical Microresonator

Physical science is rooted in measurement, but even this simple idea becomes complicated at the nanoscale. For example, how does one actually measure the charge of a single nanoparticle? Traditional electrical methods are limited to micrometer-sized objects, yet nanoparticle charge is a crucial parameter in fields spanning astronomy, optics, biochemistry, environmental engineering, and surface chemistry. In recent years, air pollution has become a severe threat to human health. The main pollution sources, including industrial dusts and chemical colloids suspended in air, are not neutral but charged.

Over the past few years, optical whispering-gallery mode (WGM) microresonators have become valuable tools in sensing applications due to the significantly enhanced light-matter interaction provided by their ultrahigh-Q factors and small mode volumes. So far, by monitoring either the cavity resonant wavelength shift (mode shift) or mode splitting, single nanoparticle binding events have been resolved. However, the sensing signal corresponds to either the size or the permittivity of particles. WGM microcavity based nanoparticle charge measurement remains unstudied.

We propose that by monitoring the transmission spectrum of a high-Q whispering gallery mode resonator, surplus charge at very low electron density can be detected. A single nanoparticle adsorbed to the resonator results in mode splitting of the two initially degenerate whispering gallery modes through backscattering. Because of the modification of nanoparticle conductivity induced by the surplus electrons, both the nanoparticle-WGM coupling strength and the dissipation changes accordingly compared with the case of a neutral nanoparticle. The charge density of the nanoparticle can be inferred by monitoring the mode splitting, the linewidth broadening, or the resonance dip value of the transmission spectrum of the microcavity. Because of the ultranarrow resonance linewidth and small mode volume of the microresonator, measurement of surface and bulk charge with very low charge density is realized.

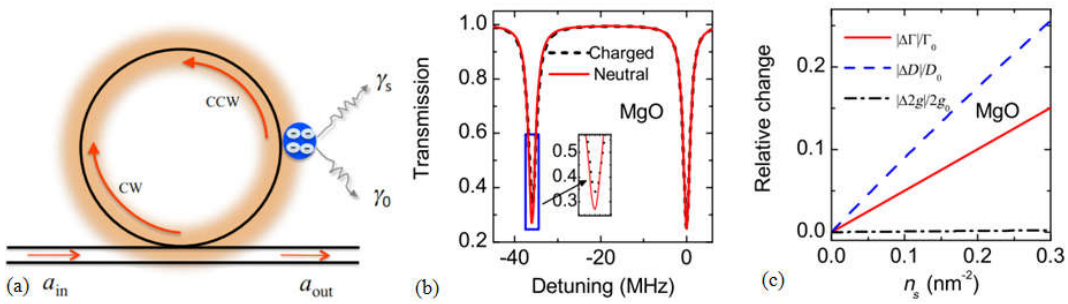

Fig 1. (a) Schematic illustration of a WGM microresonator with a charged nanoparticle attached to its surface. γ_s is the Rayleigh scattering loss, and γ_0 represents the Ohmic loss. CW and CCW are the clockwise and counterclockwise propagating modes. (b) Transmission spectrum for a WGM microcavity with a single attached neutral (red solid line) and charged MgO nanoparticle (black dashed line). (c) The MgO nanoparticle surplus charge-induced relative change of symmetric mode's linewidth (red solid line), dip value (blue dashed line), and mode splitting (black dash-dotted line) with respect to the neutral case.