Nano-sensing with a Silica Microtoroid

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Abstract: We report nano-detection using a silica microtoroid with a reference interferometer. Single polystyrene nano-beads at a record 12.5nm radius are detected; Influenza-A virion binding events with signal-to-noise ratio exceeding 38:1 are observed.

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1. Introduction

Ultra-high quality factor (Q) whispering-gallery-microcavities (WGMs) provide high-sensitivity nano-particle detection. To date, several groups have reported detection of nano-particles or virus binding events by monitoring the change of cavity-resonance wavelength [1]. In this work, a silica microtoroid [2] having a Q as high as 200 million in aqueous solution is applied to detect calibrated nano particles and InfA virion. In this Q regime, the probe laser jitter becomes a dominant noise component that limits the detection sensitivity to order 10 femtometers of wavelength shift, thereby setting the minimum detectable particle size to about 50nm radius. Recently, Shopova, et. al. demonstrated detection of 36nm radius polystyrene beads with an newly developed low, jitter-noise laser [1]. To further overcome this obstacle we present here a scanning reference interferometer technique to monitor the laser wavelength change in real time. With this technique, a resonance wavelength shift can be tracked with a demonstrated sensitivity of 0.2 femtometer. Using our method, detection of polystyrene beads at a record radius of 12.5nm is demonstrated. Moreover, single Influenza-A virion (50nm radius equivalent) is detected with more than ten-fold, signal-to-noise enhancement compared to previous reports [1]. The technique requires no stabilization of the probe laser source. Also, as cavities typically display a pair of split resonance modes, tracking the average resonance shifts of both modes as well as their relative shifts provides an independent verification of single nano-beads binding events [3].

2. Experimental Results

The measurement setup is shown in Fig. 1(a). A tunable probe laser is coupled into a directional coupler. The coupler splits the beam into two branches. One of these is connected to a tapered fiber to couple light into and out of a microtoroid. The transmitted light is received by a photo detector and displayed on an oscilloscope. The other output of the coupler is connected to a fiber-optic reference interferometer thermally stabilized in ice water. The reference interferometer is formed using 50/50 bidirectional couplers and a pair of fiber-optic delay line. The interferometer dual outputs are sent to a balanced photo detector, and then read by an oscilloscope. In a measurement, the probe laser wavelength is swept using a linear ramp, and the microtoroid resonance transmission is displayed on the inset of Fig. 1(c). (The actual spectral shape is a split resonance on account of backscatter.) Instead of using the ramp voltage signal (as is typically done), the probe laser wavelength is determined by the signal from the stabilized interferometer. This directly measures the laser wavelength at the time that it is sweeping the microtoroid resonance, and greatly reduces the impact of probe laser jitter.

In the experiments, nano-beads having radii of 50, 25 and 12.5 nm are diluted in a phosphate buffered saline. The red curve of Fig. 1(b) shows the measured microtoroid resonance versus time when 50 nm beads are injected (Q is 8.0×10^6). A maximum step-like resonance wavelength shift of 12.3 fm appears at 56.2 seconds as well as a downward shift of the same step size at 60 seconds (indicating an unbinding event of the same bead). Along the same scan, smaller steps can also be seen at 31.4 and 44.2 seconds. For comparison, the grey curve is the measured wavelength shift using the conventional (scan voltage) technique. Scan results using 12.5nm-radii nano-beads are displayed as the blue curve in the same figure (Q is 1×10^8). To improve signal-to-noise, a 3-point moving average is performed in this scan. A step of 0.4 ± 0.2 fm is observed at 11 seconds (see inset I). By monitoring one of the two, split spectral peaks (as opposed to the average location of the split resonances), an even larger signal is observed (see inset II). In this case, a 1.0 ± 0.2 fm step is observed for the same event. This useful effect happens

because of the compounding effect of both backscatter-induced and path-length induced shifts. To further illustrate, the split frequency shift of the same event in provided in inset III of Fig. 1(b). Compiled resonance shifts for many trials using three bead sizes are presented in Fig. 1(c). The maximum shifts are in good agreement with predictions. Lastly, in Fig. 1(d) the binding of an Influenza A (InfA) virion (step of 11.3 ± 0.3 fm magnified in inset) is observed with an SNR of 38:1. A histogram plot of step size is displayed in main plot of fig. 2(b). More events of positive step size than the negative size suggests a stronger affinity force.

3. Conclusion

We demonstrate that by adopting a reference interferometer to monitor the whispering gallery resonance wavelength in real time, the impact of laser wavelength jitter can be substantially reduced. Sensing of a record minimum nano-bead size of 12.5nm in radius is achieved; and InfA-virion detection signal-to-noise ratio has been enhanced by more than 10 times to 38:1. This method is ready to apply to other platforms such as microsphere and microdisk sensors.

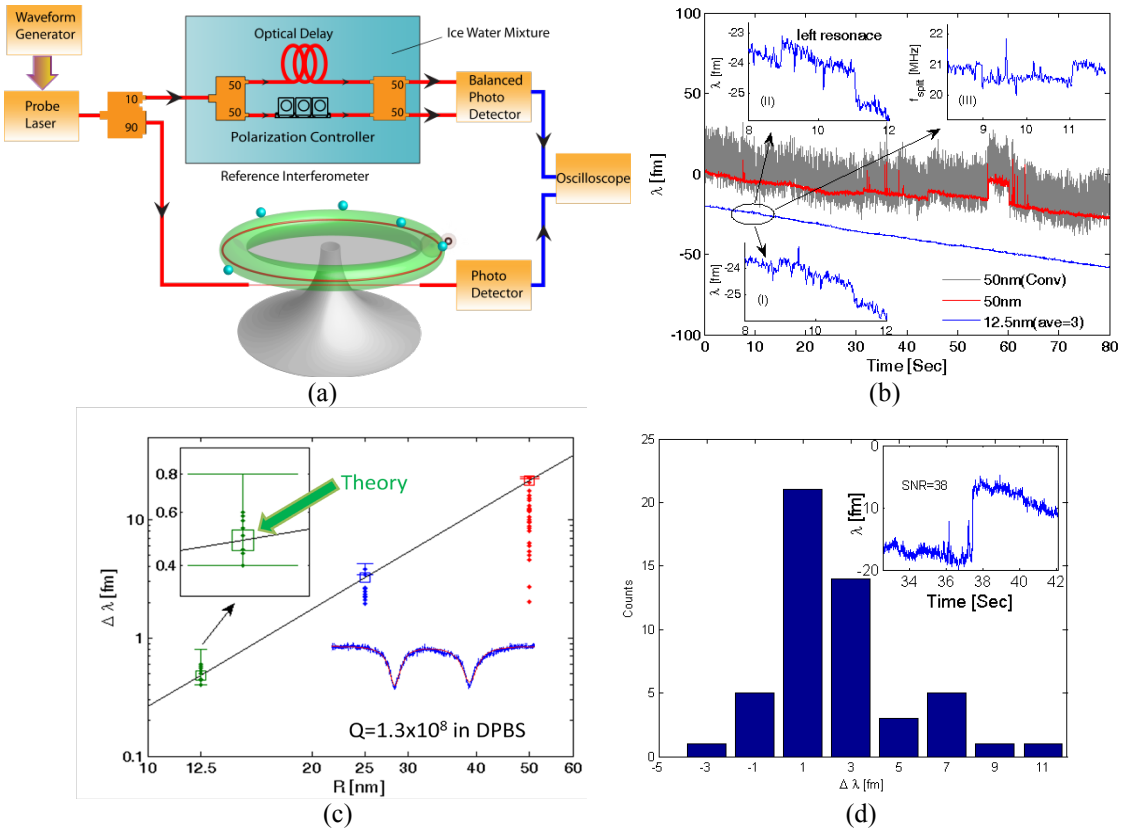

Fig. 1 (a) Experiment setup. (b) Resonance wavelength shift vs. time of R = 50 nm (red) and R =12.5 nm (blue) polystyrene nano-beads. In R = 12.5 nm bead experiments, the shift is recorded with a 3-point moving average. For comparison, the trace in grey is the same data run as the one in red, only using the conventional sweep-voltage method. (c) Collected resonance shift steps of R=50nm (red), R=25nm (blue) and R=12.5nm (green) beads. The squares are the theoretical maximum shifts. (d) A histogram of measured resonance wavelength shift steps for InfA virion detection. Inset: A measured InfA virion resonance shift step of 11.3±0.3 fm.

References

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