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Microbubble resonators for photoacoustic and photothermal characterisation of nanoparticles suspensions

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Abstract. We discuss the implementation of Whispering Gallery Modes Microbubble resonators (MBRs) as unique platforms for photoacoustic (PA) detection and photothermal (PT) spectroscopy. In a first experiment, the MBR transducer allowed to detect the PA signal generated by a suspension of gold nanorods (GNRs) within its core, leveraging on the MBR sharp optical spectrum and high sensitivity towards mechanical perturbations. Both static and flow-cytometry configuration were tested, finding that the MBR mechanical modes help detection by decoupling the environmental noise from the PA oscillation. In a second experiment, the MBR transducer allowed to reconstruct the GNRs absorption spectrum through the photothermal (PT) conversion, leveraging on high sensitivity towards temperature variations. We verified the scattering-free nature of the detection by using milk-stained GNRs suspension. We also found that the active locking of the MBR resonance increases the system sensitivity by an order-of-magnitude. These results make MBRs interesting candidates for combined PA and PT characterisation of extremely small samples for medical diagnosis, quality controls in food safety and chemical production processes.

1 Introduction

In this work we discuss the implementation of microbubble resonators (MBRs) as all-optical transducers for the photoacoustic (PA) and photothermal (PT) characterisation of nanoparticles suspensions. Before discussing the main results in Section 2, we briefly resume here PA detection and PT spectroscopy.

The photoacoustic (PA) effect is the conversion of a light pulse into an ultrasound pulse, mediated by optical absorption and thermoelastic expansion. This effect is used in non-invasive medical imaging (PA imaging) to reconstruct the structure of biological tissues (e.g. blood vessels) or in flow cytometry to detect the presence of anomalous cells (e.g. blood clots, tumour cells). In these applications, the ultrasound wave is typically collected through a piezoelectric transducer. Since this technology does not allow for miniaturization without performance degradation, the development of optical transducers is being investigated [1], because they could allow for wider detection bandwidths and higher temporal and spatial resolutions. Integrated microrings have proved to be effective in the context of PA imaging: with our MBR transducer we focus on the flow-cytometry context. Moving to photothermal (PT) spectroscopy, one can define it as a series of optical methods used to measure the heat evolution within an irradiated sample with the aim of reconstructing its absorption spectrum [2]. Even in this case, optical technologies represent interesting platforms for temperature and heat detection, since they can provide high sensitivity, high spatial and temporal resolution, multiplexing and remote sensing. Optical resonators appear particularly promising in this context, since recent works have demonstrated PT spectroscopy on a single particle in dry environments over a reduced spectral range [3].

In this context we propose microbubble resonators (MBRs) as all-optical transducers for both PA detection and PT spectroscopy, leveraging on their unique features. In particualr, MBRs belong to the family of Whispering Gallery Modes Modes (WGMs) resonators, which are optical resonators with cylindrical symmetry and submillimetric footprint. MBRs, just as the other WGMs resonators, have a sharp optical spectrum and high-finesse resonances, which make them promising in non-linear optics (e.g. frequency generation, cavity optomechanics) as well as optical sensing. In addition, since MBRs are produced by inflating a glass capillary, they also have intrinsic microfluidics and mechanical resonances, which make them promising optical transducers for the characterisation of liquid samples hosted within their core. Here, we show the results of two proof-of-concept experiments, where MBRs were used to characterise the PA and PT response of an aqueous suspension of Gold NanoRods (GNRs) [4]. These nanoparticles were chosen since they are a reference standard in PA applications. In both ex-

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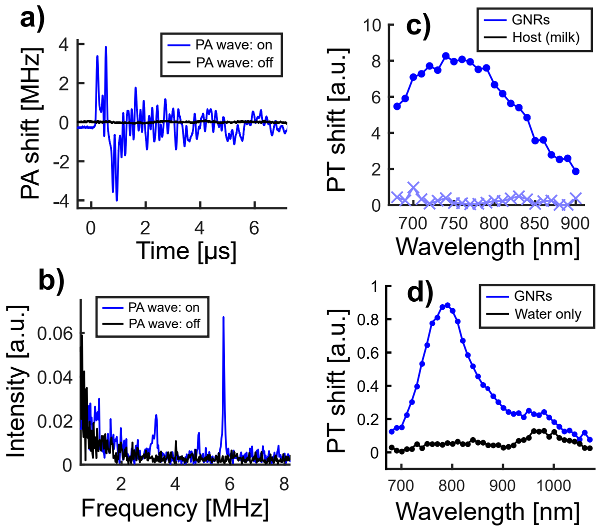

Figure 1. a) Optical shift induced by a PA wave in a static configuration. b) Fourier transform of PA signals during flow-cytometry. c) PT spectrum in GNR suspension stained with milk. d) PT spectrum obtained with active lock of the resonance.

periments, the GNRs response was measured through the optical shift induced in the MBR spectra.

2 Experiment results

In the first experiment the PA response of the GNRs suspension was studied [5, 6]. In practical terms, the GNRs suspension within the MBRs was excited with a high-fluence pulsed source to trigger the PA wave, and the position of an MBR resonance was monitored using a tunable narrow-line probe laser [5]. Figure 1a shows the typical optical shifts that the PA wave induces in a MBR resonance. The dipolar trend is indeed consistent with the general trend of PA signals wave and the peak-to-peak value showed the correct scaling with respect to the fluence of the excitation source [5]. After this initial test, we also simulated a flow-cytometry configuration by flowing continuously the GNRs during the measurements [6]. In this case, we used the Fourier transforms of the signals to detect the PA oscillation, because the mechanical modes of the MBR allowed to easily decouple the PA oscillation from the flow noise (Figure 1b).

In the second experiment, the PT response of the GNRs suspension was studied [7, 8]. At variance with the first experiment, a filtered supercontinuum source with low-fluence was used to excite the GNRs. This allowed to induce a gentle increase in temperature, rather than an ultrasound pulse. The temperature-induced resonance shift was measured with the same probe laser and, by collecting the shifts at various excitation wavelengths, the absorption spectrum of the GNRs was reconstructed (Figure 1c). To prove the system insensitivity towards scattering phenomena within the sample, we also repeated the experiment with a suspension stained by milk powder [7]. By introducing an active locking system for the MBR resonance, the detection sensitivity increased by an order of magnitude and the absorption peak was better reconstructed (Figure 1d) [8].

3 Conclusions

In conclusion, we have shown the implementation of MBRs as sensitive all-optical transducers for the PA and PT characterisation of nanoparticles. Our implementation leverages on the unique features of the MBRs: sharp optical spectrum, intrinsic microfluidics, presence of mechanical resonances, scattering free-detection and extremely small footprint. In the end, MBRs hold promise for combined PA and PT characterisation of extremely small samples in the context of medical diagnosis from whole biological samples, quality controls in food safety and chemical production processes.

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