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Ultrafast Nano Generation of Acoustic Waves in Water: Thermophone versus Mechanophone

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Nanoscale photothermoacoustics generation in liquids, by reason of its implications in nanoimaging and therapeutic, is a booming topic at the forefront of nanoscale heat transfer, optics and biosciences [1]. Within this frame, liquid-immersed nanotransducers play a major role as efficient photoacoustic generators because of their biocompatibility together with tunable optical absorption properties. Research efforts focused on enhancing photoacoustic conversion acting on the nano transducers' materials, geometry and size. Despite these efforts and the applicative interest, the effects of the Kapitza resistance and the laser pulse duration on the acoustic wave generation mechanism [2-4] are yet to be fully uncovered and lack of a thorough understanding.

Within this context, we review recent developments on the photothermoacoustic of water-immersed gold nanocylinders and nanofilms. The focus is on the acoustic waves launching mechanisms and their competition. We demonstrate that the acoustic waves are not only launched by the expansion of water- "thermophone effect", but also by the expansion of the nano-object itself- "mechanophone effect". Both the thermal dynamics and the mechanical response are systematically addressed. The physical parameters controlling the thermophone vs mechanophone competition are identified together with their interplay [5].

We then extend the investigation to the photoacoustic effect of water-immersed carbon nanotubes, combining microscopic atomistic simulations, analytical models and finite element methods [6]. In this case, in addition to the thermophone vs mechanophone competition, we show how the activation of the mechanophone effect can trigger few nanometers wavelengths sound waves in water.

Our findings suggest the possibility to exploit liquid-immersed nano-transducers, characterized by a high Kapitza resistance, to launch acoustic waves in the liquid while minimizing their temperature increase. This strategy is at variance with what usually suggested in the literature, i.e. minimizing the Kapitza resistance, and is foreseen to play a role in bio-imaging applications at the nano- scale where high frequency acoustic wave generation in water is required while avoiding heating effects. These findings find generalization also in all-solid state systems [7,8].

References

- [1] S. Y. Emelianov, P.-C. Li, and M. O'Donnell, "Photoacoustics for molecular imaging and therapy ", *Phys. Today* **62**, 34 (2009).
- [2] A. Prost, F. Poisson, and E. Bossy, "Photoacoustic generation by a gold nano- sphere: From linear to nonlinear thermoelastics in the long-pulse illumination regime", *Phys. Rev. B* **92**, 115450 (2015).
- [3] M. Gandolfi, F. Banfi, and C. Glorieux, "Optical wavelength dependence of photoacoustic signal of gold nanofluid", *Photoacoustics* **20**, 100199 (2020).
- [4] G. A. Pang, F. Poisson, J. Laufer, C. Haisch, and E. Bossy, "Theoretical and experimental study of photoacoustic excitation of silica-coated gold nanospheres in water ", *J. Phys. Chem. C* **124**, 1088 (2020).
- [5] M. Diego, M. Gandolfi, S. Giordano, F. Violla, A. Crut, F. Vallée, P. Maioli, N. Del Fatti, and F. Banfi, "Tuning photoacoustics with nanotransducers via thermal boundary resistance and laser pulse duration", *Appl. Phys. Lett.* **121**, 252201 (2022).
- [6] M. Diego, M. Gandolfi, A. Casto, F.M. Bellussi, F. Violla, A. Crut, S. Roddaro, M. Fasano, F. Vallée, N. Del Fatti, P. Maioli and F. Banfi, "Ultrafast nano generation of acoustic waves in water via a single carbon nanotube", *Photoacoustics* **28**, 100407 (2022).
- [7] M. Gandolfi, S. Peli, M. Diego, S. Danesi, C. Giannetti, I. Alessandri, V. Zannier, V. Demontis, M. Rocci, F. Beltram, L. Sorba, S. Roddaro, F. Rossella, and F. Banfi, "Ultrafast Photoacoustic Nanometrology of InAs Nanowires Mechanical Properties" *J. Phys. Chem. C* **126**, 6361 (2022).
- [8] M. Bertolotti and R. Li Voti, "A note on the history of photoacoustic, thermal lensing, and photothermal deflection techniques ", *J. Appl. Phys.* **128**, 230901 (2020).