The coming of age of luminescence nanothermometry

Luís D. Carlos

Phantom-G, CICECO-Aveiro Institute of Materials, Physics Department, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal,

* *lcarlos@ua.pt*

The emergence of luminescent nanothermometry during the last decade opened the possibility of measuring thermal flows at spatial scales below 1 μm, unreachable by conventional electrical methods. Diverse phosphors capable of providing remote detection through their light emission properties have been examined, e.g., polymers, DNA or protein conjugated systems, organic dyes, quantum dots, and trivalent lanthanide (Ln^{3+}) ions incorporated in organic-inorganic hybrids, multifunctional heater-thermometer nanoplatforms, upconverting, downconverting and downshifting nanoparticles.[1]

In recent years, luminescence nanothermometry has entered a more mature stage. Although new classes of thermographic phosphors continue to be reported, e.g., covalent organic frameworks[2] and single-ion magnets,[3,4] we are perceiving a gradual shift in the emphasis of the technique. The research efforts are now focused on establishing comprehensive theoretical backgrounds and standardization procedures (both in data acquisition and processing and in measurement methodologies), discussing the reliability, repeatability, and reproducibility of the technique, and developing new applications.[5]

The lecture will give a general perspective of the work done on luminescence nanothermometry since the explosion of the field one decade ago, illustrating the potential of the technology with recent examples of heat transfer at the nanoscale,[6] thermal bioimaging,[7,8] and the unveiling of the anomalous properties of liquid water.[9]

[1] C. D. S. Brites, S. Balabhadra, L. D. Carlos, Lanthanide-Based Thermometers: At the Cutting-Edge of Luminescence Thermometry, *Adv. Opt. Mater.* **7** (2019) 1801239.

[2] A. M. Kaczmarek, Y. Y. Liu, M. K. Kaczmarek, H. S. Liu, F. Artizzu, L. D. Carlos, P. Van Der Voort, *Angew. Chem. Int. Edit.* **59** (2020) 1932.

[3] R. Marin, G. Brunet, M. Murugesu, *Angew. Chem. Int. Ed.* 60 (2021) 1728-1746 (2020).

[4] R. A. S. Ferreira, E. Mamontova, A. M. P. Botas, M. Shestakov, J. Vanacken, V. Moshchalkov, Y. Guari, L. F. Chibotaru, D. Luneau, P. S. Andre, J. Larionova, J. Long, L. D. Carlos, *Adv. Opt. Mater.* 9 (2021) 2101495.

[5] C. D. S. Brites, X. Xie, M. L. Debasu, X. Qin, R. Chen, W. Huang, J. Rocha, X. Liu, L. D. Carlos, Instantaneous ballistic velocity of suspended Brownian nanocrystals measured by upconversion nanothermometry, *Nature Nanotech.* **11** (2016) 851.

[6] A. R. N. Bastos, C. D. S. Brites, P. A. Rojas-Gutierrez, C. DeWolf, R. A. S. Ferreira, J. A. Capobianco, L. D. Carlos, *Adv. Funct. Mater.* 29 (2019), 1905474.

[7] R. Piñol, J. Zeler, C. D. S. Brites, Y. Gu, P. Téllez, A. N. Carneiro Neto, T. E. da Silva, R. Moreno-Loshuertos, P. Fernandez-Silva, A. Isabel Gallego, L. Martinez-Lostao, A. Martínez, L. D. Carlos, A. Millán, Real-Time Intracellular Temperature Imaging Using Lanthanide-Bearing Polymeric Micelles, *Nano Lett.* **20** (2020) 6466.

Local Temperature Increments and Induced Cell Death in Intracellular Magnetic Hyperthermia

[8] Y. Gu, R. Piñol, R. Moreno-Loshuertos, C. D. S. Brites, J. Zeler, A. Martínez, G. Maurin-Pasturel, P. Fernández-Silva, J. Marco-Brualla, P. Téllez, R. Cases, R. N. Belsué, D. Bonvin, L. D. Carlos, A. Millán, *ACS Nano* **17** (2023) 6822.

[9] C. D. S. Brites, B. Zhuang, M. L. Debasu, D. Ding, X. Qin, F. E. Maturi, W. W. Y. Lim, D. W. Soh, J. Rocha, Z. Yi, X. Liu, L. D. Carlos, Decoding a Percolation Phase Transition of Water at ~330 K with a Nanoparticle Ruler, *J. Phys. Chem. Lett.* **11** (2020) 6704.