Opto-Electrothermal Control of Polystyrene Microparticles in Microfluidic Systems

Emad Khalfalla [1,2], Emilio Ruiz-Reina [3], Raúl A. Rica-Alarcón [1]

[1] Universidad de Granada, Department of Applied Physics, Nanoparticle Trapping Laboratory, Granada, Spain
[2] Department of Mechanical and Industrial Engineering, Faculty of Engineering, University of Zawia, Libya
[3] Department of Applied Physics II, University of Málaga, Málaga, Spain

emadk@zu.edu.ly

The control of particles and/or fluid flow at the microscale using optical and electric fields has become a central topic in microfluidics and lab-on-a-chip techniques [1-3]. In this study, we investigate the behavior of polystyrene particles in an electrolyte solution under simultaneous laser irradiation and an applied electric field in a microfluidic platform [4,5].

Experiments were conducted with different chip geometries and electrode configurations, including both commercially manufactured and in-house designs, to study the generation of electrothermal flow and its use to control suspended microparticles in a commercial optical tweezers device. The position of the laser relative to the sample was systematically varied to investigate its influence on particle motion and fluid dynamics. High-speed imaging was used to capture the particle trajectories, which were subsequently analyzed using custom Python-based routines to extract motion patterns, velocity distributions, and statistical properties of the system.

The analysis shows the occurrence of ordered and directed flow structures in particle motion. The observed dynamics indicate a strong coupling between optical heating and electric field effects, leading to thermoelectrically driven transport. It was shown that changes in the laser position significantly influence the flow behavior, suggesting a strong dependence on the local temperature gradient and field distribution.

These results underline the importance of combined photoelectric effects for controlling particle motion and provide valuable insights to improve retention and transport mechanisms in microfluidic systems.

Keywords:

Electrothermal flow
Microfluidics
Microelectrodes
Optical tweezers

References:

[1] Ndukaife, J. C., Mishra, A., Guler, U., Nnanna, A. G. A., Wereley, S. T., & Boltasseva, A. (2014). Photothermal heating enabled by plasmonic nanostructures for electrokinetic manipulation and sorting of particles. ACS nano, 8(9), 9035-9043.
[2] Schmidt, F., González-Gómez, C. D., Sulliger, M., Ruiz-Reina, E., Rica-Alarcón, R. A., Ortega Arroyo, J., & Quidant, R. (2025). Three-dimensional optofluidic control using reconfigurable thermal barriers. Nature Photonics, 19(12), 1385-1391.
[3] Ndukaife, J. C., Kildishev, A. V., Nnanna, A. G. A., Shalaev, V. M., Wereley, S. T., & Boltasseva, A. (2016). Long-range and rapid transport of individual nano-objects by a hybrid electrothermoplasmonic nanotweezer. Nature nanotechnology, 11(1), 53-59.
[4] Garcia-Guirado, J., Rica, R. A., Ortega, J., Medina, J., Sanz, V., Ruiz-Reina, E., & Quidant, R. (2018). Overcoming diffusion-limited biosensing by electrothermoplasmonics. Acs Photonics, 5(9), 3673-3679.
[5] González-Gómez, C. D., Rica, R. A., & Ruiz-Reina, E. (2023). Electrothermoplasmonic flow in gold nanoparticles suspensions: Nonlinear dependence of flow velocity on aggregate concentration. Journal of Colloid and Interface Science, 648, 397-405.