Droplet-based Microfluidics and Optofluidics: smart tools for the synthesis and analysis of advanced materials in photonics and plasmonics

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Droplet-based microfluidics allows for the production and the manipulation of highly monodisperse microdroplets of fluids, with a high degree of control and reproducibility, each of which may be regarded as an independent microreactor: high throughput parallelization can be realized in the vessels that can be complemented by sophisticated analysis, or, the screening of a single compound can be performed at different concentrations and kHz rates. Many applications have been developed during the last two decades using microfluidics. Optofluidics is a contraction of optics and microfluidics. It aims at manipulating light and confined fluids in micro-droplets and exploiting their interaction to create "digital" micro-systems with highly significant scientific and technological interests in many areas, from single-cell studies and genetic sequencing to photonics. Microdroplets are generally stabilized by surfactants, which play a key role in the process of molecular exchange between droplets. Microdroplets can be also condensed individually using suitable condensation process to give rise to highly monodisperse solid or gel-like microspheres or microcapsules. The prospects offered hence by droplet-based microfluidics and optofluidics are numerous and concern many fundamental and industrial fields in biology, physics, chemistry, material science, etc. The combination of emulsion solvent evaporation technique and droplet-based microfluidics allows for the synthesis of well-defined monodisperse microcapsules (hollow microspheres) with different types of nanoparticles used as building blocks, e. g. silica, ZnO, TiO_2, etc. Such microparticles may find very interesting applications as photocatalysts. These are inorganic semiconductors, which under light illumination generates an electron-hole pair capable of promoting redox reactions of depollution, photocleavage or artificial photosynthesis for H_2 fuel production. In order to better exploit the visible light energy (50 % of the solar spectrum), a new generation of photocatalysts based on surface plasmon resonance (SPR) effect has been developed in recent years. The so-called plasmonic photocatalysts usually comprise semiconductor materials which are transparent in the visible range, such as TiO_2, and plasmonic nanoparticles such as gold nanoparticles (Au NPs). Specific SPRs, though, only partially cover the visible spectrum and feature weak light absorption. It has been demonstrated recently by several groups, theoretically and experimentally, that the visible light activity of plasmonic photocatalysts could be increased significantly when whispering gallery mode resonances (WGMs) are induced in the semiconductor particles, due to total internal refection of the light along the curved surface of such particles. Accordingly, such WGMs plasmonic photocatalysts, when employed in water splitting experiments, for instance, exhibit enhanced activity in the visible range. Unfortunately, the experimental demonstration of this phenomenon is still hampered by the difficulty of synthesizing semiconductor particles that are highly monodisperse and perfectly spherical, as WGMs are induced only when light is confined in perfect spherical cavities. Using microfluidics, the size, thickness, shape and composition may be finely and easily controlled. In this talk, I will focus more particularly on the crucial role played by the surfactants used for controlling either the mesoporosity of synthesized microparticles and their optical properties using WGMs resonances in spherical microcavities. In such optical micro-resonators, light propagate in the form of WGMs as a result of the total internal reflection of light along the curved surface of microdroplets.

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