DESIGN OF HYBRID SILICA NANOSTRUCTURES: FROM CONTROLLED SYNTHESIS TO TARGETED THERAPEUTIC APPLICATIONS

Maria Lucia Curri[1,2,3], Federica Rizzi[2,3], Rita Mastrogiacomo[1,2], Maria Principia Scavo[4], Ilaria Palamà,5 Marinella Striccoli[2], Annamaria Panniello[2], Gianluca Minervini[2], Roberto Comparelli[2,3], Elisabetta Fanizza[1,2,3], Nicoletta Depalo[2,3]

[1]Chemistry Dept, University of Bari, Via Orabona 4, Bari, 70126, Italy, marialucia.curri@uniba.it; [2]CNR IPCF Institute for Physical and Chemical Processes, c/o Chemistry Dept Via Orabona 4, Bari, 70126, Italy; [3]National Interuniversity Consortium of Materials Science and Technology (INSTM), Florence, Italy, Bari Unit, Chemistry Dept, Via Orabona 4, Bari, 70126, Italy; [4]Laboratory of Personalized Medicine IRCCS deBellis Via Turi 27, Castellana Grotte (Bari), 70013, Italy; [5]CNR NANOTEC Institute of Nanotecnology c/o Campus Ecotekne, Via Monteroni 165, Lecce, 73100, Italy

Abstract: Silica nanoparticles, including compact and mesoporous architectures, provide a versatile and biocompatible platform for biomedical and technological applications. Their tunable structural and chemical properties enable precise control over size, morphology, and surface chemistry, facilitating the design of multifunctional systems for drug delivery, imaging, and theranostics.

We have employed compact silica nanoparticles as solid cores in hybrid nanostructures, incorporating functional elements such as luminescent, plasmonic and magnetic nanocrystals.[1,2] Additionally, we engineered mesoporous silica nanostructures (MSNs) with high surface area, tunable morphology, and large pore volumes to encapsulate therapeutic molecules and functional nanoparticles.[3] Functionalization of the silica surface with targeting ligands was implemented to achieve precise cellular and subcellular delivery, thereby enhancing the multifunctionality of MSNs through integration of diagnostic, therapeutic, and targeting capabilities within a single nanocarrier.[4,5]

Stimuli-responsive features significantly expand the versatility of silica platforms. For example, we developed core@shell SiO_2@MSNs engineered for pH-triggered drug release and targeted colorectal cancer therapy, which also incorporated imaging agents. Similar core@shell structures containing photothermal components showed antimicrobial activity under near-infrared light.[6] Moreover, we adapted both SiO_2@MSNs and hollow MSNs as gene delivery vectors, observing excellent colloidal stability and in vitro biocompatibility.

Our development of these nanomaterials relied on precise control of synthetic parameters to tailor size, porosity, and stability for optimal cellular uptake. Integrated physicochemical characterization offered crucial insights that guided the rational refinement of their biomedical performance. This presentation will showcase our materials-by-design strategy, demonstrating how meticulous synthesis, functionalization, and comprehensive characterization come together to create multifunctional silica nanoplatforms. We will discuss selected case studies from our work highlighting the versatile potential of silica nanotechnology in biomedical research.

Key words: *mesoporous silica nanostructures (MSNs), multifunctional nanocarriers, targeted drug/gene delivery, stimuli-responsive systems*

Acknowledgement: The work has been partially supported by Bilateral Project CNR-RFBR Russia Joint research project (2021-2024), TITAN- PON ARS01_00906, NHYLODEA - European Union - Next Generation EU, Mission 4 C 1, CUP H53D23007980001, "Handling of mesenchymal-like circulating pancreatic cancer cells as an innovative approach to restrain disease progression" PNRR-MCNT2-2023-12377885- European Union - Next Generation EU, Mission 6 C 2, CUP F53C23001360008.

REFERENCES

[1] G. Siciliano et al., "Gold-speckled SPION@SiO_2 nanoparticles decorated with thiocarbohydrates for ASGPR1 targeting: towards HCC dual mode imaging potential applications", Chemistry–A European Journal, 26, 11048-11059, 2020.

[2] E. Fanizza et al., "NIR-Absorbing Mesoporous Silica-Coated Copper Sulphide Nanostructures for Light-to-Thermal Energy Conversion", Nanomaterials, 12, 2545, 2022.

[3] F. Rizzi et al., "High Surface Area Mesoporous Silica Nanoparticles with Tunable Size in the Sub-Micrometer Regime: Insights on the Size and Porosity Control Mechanisms", Molecules, 26, 4247, 2021.

[4] N. Depalo et al., "NIR emitting nanoprobes based on cyclic RGD motif conjugated PbS quantum dots for integrin-targeted optical bioimaging", ACS Appl. Mater. Interfaces, 9, 43113–43126, 2017.

[5] E. Fanizza et al., "Highly selective luminescent nanostructures for mitochondrial imaging and targeting", Nanoscale 8, 3350-3361, 2016.

[6] F. Rizzi et al., "Mesoporous silica nanostructures embedding NIR active plasmonic nanoparticles: Harnessing antimicrobial agents delivery system for photo-assisted eradicating Gram-positive bacteria", Microporous and Mesoporous Mater. 383, 113414, 2025.