Hydrogel Formation via NIR-Induced Polymerization in Upconversion-Activated Macroporous Silica Backbone

Hyunmin Cho[1], and Joonseok Lee[1],*
[1] *Department of chemistry, Hanyang University, Seoul 04763, Republic of Korea*
hm2025@hanyang.ac.kr

Photopolymerization is widely used in the fabrication of functional hydrogel systems due to its site-specific and temporally tunable reaction, fast polymerization rate, and adaptability to diverse material systems. However, conventional ultraviolet (UV)-initiated polymerization is fundamentally limited by poor optical penetration and uncontrolled reaction kinetics, often leading to fragile polymer structures and network heterogeneity. These limitations restrict its use in deep tissue, optically challenging, and mechanically demanding environments. To address these limitations, we propose a near-infrared (NIR)-induced polymerization strategy based on a NIR-activated silica backbone (NASB), which enables enhanced light penetration, improved mechanical properties, and spatial control over polymerization. Within this NASB system, the silica framework features a macroporous architecture with accessible pores and a particle size exceeding 800 nm, providing a high surface area and structural capacity for upconversion nanoparticle (UCNPs, ≈60nm) immobilization. This structural characteristic facilitates matrix entanglement during upconversion-induced polymerization initiated by UV emission from NIR-excited UCNPs. In addition, UCNPs immobilized along the pore walls of the silica framework guide polymerization in close proximity to the structure, further enhancing the network strength of the hydrogel network. This strategy improves mechanical performance through material-guided polymerization, expanding the potential of photoinduced hydrogel fabrication.

References

[1] E. Jeon, S. H. Kim, S. Kim, D. S. Ryu, J. W. Kim, K. Kim, D. H. Kim, J.-H. Park and J. Lee, Adv. Mater, 37 (2025) 2414944.
[2] Hu, P., Xu, H., Pan, Y. et al. Nat. Commun, 14 (2023) 3653

Figures

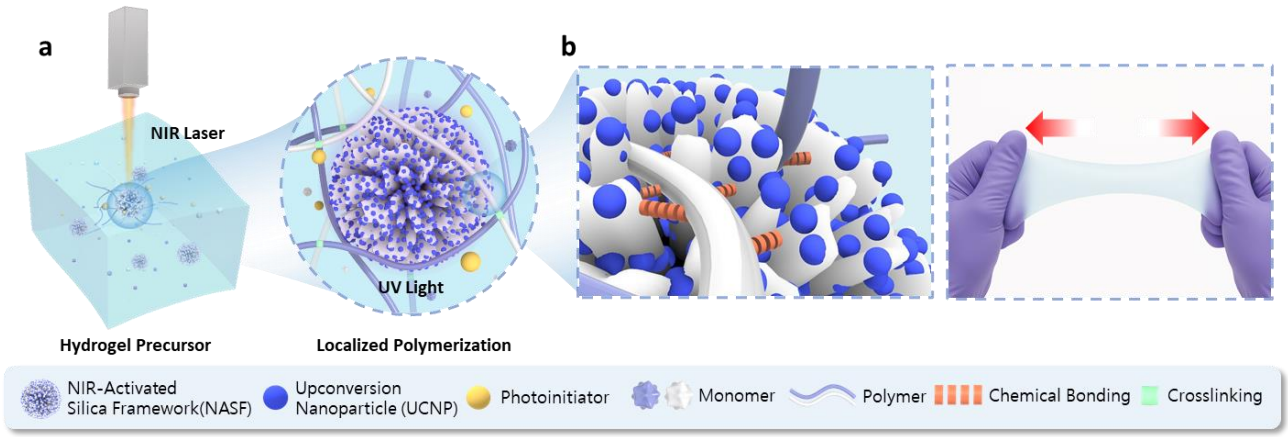

Figure 1: Schematic illustration of spatially confined hydrogel polymerization initiated by UV emission from a NIR-activated silica framework (NASF), composed of porous silica nanoparticles with immobilized UCNPs, under 980 nm laser irradiation.