Tuning the morphology of smart hybrid mesoporous silica nanoparticles

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The ideal vehicle for smart delivery systems should be able to accommodate large payloads and feature a smart release control mechanism that allows on-demand delivery of its cargo. Such systems have a variety of applications, including precision agriculture, environmental remediation, corrosion control and drug delivery. In the latter case, the vehicle should also have traceability features to enable it to be followed and targeting features to deliver the cargo to a desired location.

Our vision for the ideal smart delivery vehicle is based on hybrid polymer@silica nanocarriers with a shell of responsive polymers and a silica nanoparticle core. The core, which is based on mesoporous silica nanoparticles (MSNs), offers high mechanical stability, well-defined particle morphology, tunable particle diameter and pore size (to accommodate the cargo), versatile functionalization (internal versus external surface) and good colloidal stability. Smart polymers, on the other hand, can respond to a dynamic environment; the fluctuation of stimuli over time induces a modulated response in the polymer chain conformation and interactions, which are activated by a trigger such as temperature, pH or proteins. This provides pore gating for active release control, modulating interactions with the environment. In specific applications, it improves biocompatibility and provides specific cell targeting. In our group we have worked on the two main components of this hybrid systems: smart polymeric shell and mesoporous silica core

In the case of smart polymeric shell, we have shown how to modify MSNs at the external surface with a polymer shell featuring conformational changes induced by temperature or pH,[1] that can act as precise gatekeepers to control cargo release from the MSNs pore system. The nanoparticles can feature either a polymer brush or a gel-like responsive shell, produced by grafting-from RAFT polymerization that offers low size dispersity. Additionally, the internal surface can be modified to interact preferentially with the cargo to decrease leakage in the “off” release state,[2] or incorporate ions in the silica network for hierarchical release.[3] In a different approach, we developed hybrid polymer-silica nanoparticles based on a polymer shell of biocompatible poly(lactide-co-glycolide) (PLGA) grown by surface-initiated ring opening polymerization (ROP) from a fluorescent silica core, allowing the release of anticancer drug doxorubicin through selective cell-triggered PLGA enzymatic degradation.[4]

For the preparation of MSNs with diameters in the range of a few tens of nanometres and narrow size dispersion, we have developed a fully controllable aqueous low temperature sol-gel method for the preparation of MSNs with user-defined diameters from 15nm to 80nm.[5] The control was achieved by tuning the colloidal stability of the cylindrical micelle assembly that templates MSN synthesis. This was done using cylindrical CTAB micelles at different pH levels. We also realised that adding NaCl at a constant pH (which affects ionic strength and charge screening) tunes the specific interactions of salt counterions with surfactant head groups, thereby affecting their self-assembly properties through intra- and intermolecular forces.

In the final part of this communication, we will present our efforts to expand the range of ionic compounds used to produce MSNs with different morphologies, which are caused by variations in the solvation layer around the micelles. We have rationalized these results using the Hofmeister series, which classifies anions according to their hydration properties. Well-hydrated anions (kosmotropic) destabilize the hydrogen bonds between water and the polar groups of the template micelles, thereby increasing the cost of hydration. This results in the dehydration of the micelle corona, increasing micelle aggregation and, consequently, the final particle.

References

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