

Programming polymers with protein-like precision: How do monomer sequence and stereochemistry shape structure?

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The ability to design both the structures and properties of proteins has revolutionized molecular science, culminating in the 2024 Nobel Prize in Chemistry for breakthroughs in protein design. This milestone highlights the power of precise sequence and stereochemical control in crafting functional macromolecules. Yet, can we extend this precision to non-biological polymers and create synthetic macromolecules that mimic the folding and functions of proteins?

Recent advances in precision polymer synthesis allow for the fabrication of abiotic macromolecules with well-defined monomer sequences, unlocking new possibilities for polymer engineering.[1] Sequence-defined polymers have the potential to adopt controlled secondary structures, just like their biological counterparts, and thus acquire specific functionalities. In this talk, I will present our work on polyurethanes and discuss synthetic pathways to control monomer order and stereochemistry [2]. By fine-tuning the sequence of chiral monomers, we can dictate chain mobility [3], folding, and self-assembly. Remarkably, we demonstrate that the secondary structure of polyurethanes—whether helical or sheet-like—can be directly programmed by the stereosequence of monomers.

Beyond structural organization, stereocontrol influences key functionalities, such as binding strength in ligand-polymer complexes [4] and catalytic properties. Our findings suggest that these precisely engineered macromolecules can exhibit receptor-like and enzyme-like behavior, marking a step toward developing artificial proteins built on an abiotic polyurethane backbone. This work paves the way for programming synthetic polymers with biomimetic capabilities, offering exciting prospects for materials science, molecular recognition, and catalysis.

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