Femtosecond laser technique births 'dancing microrobots': A breakthrough in multi-material microfabrication

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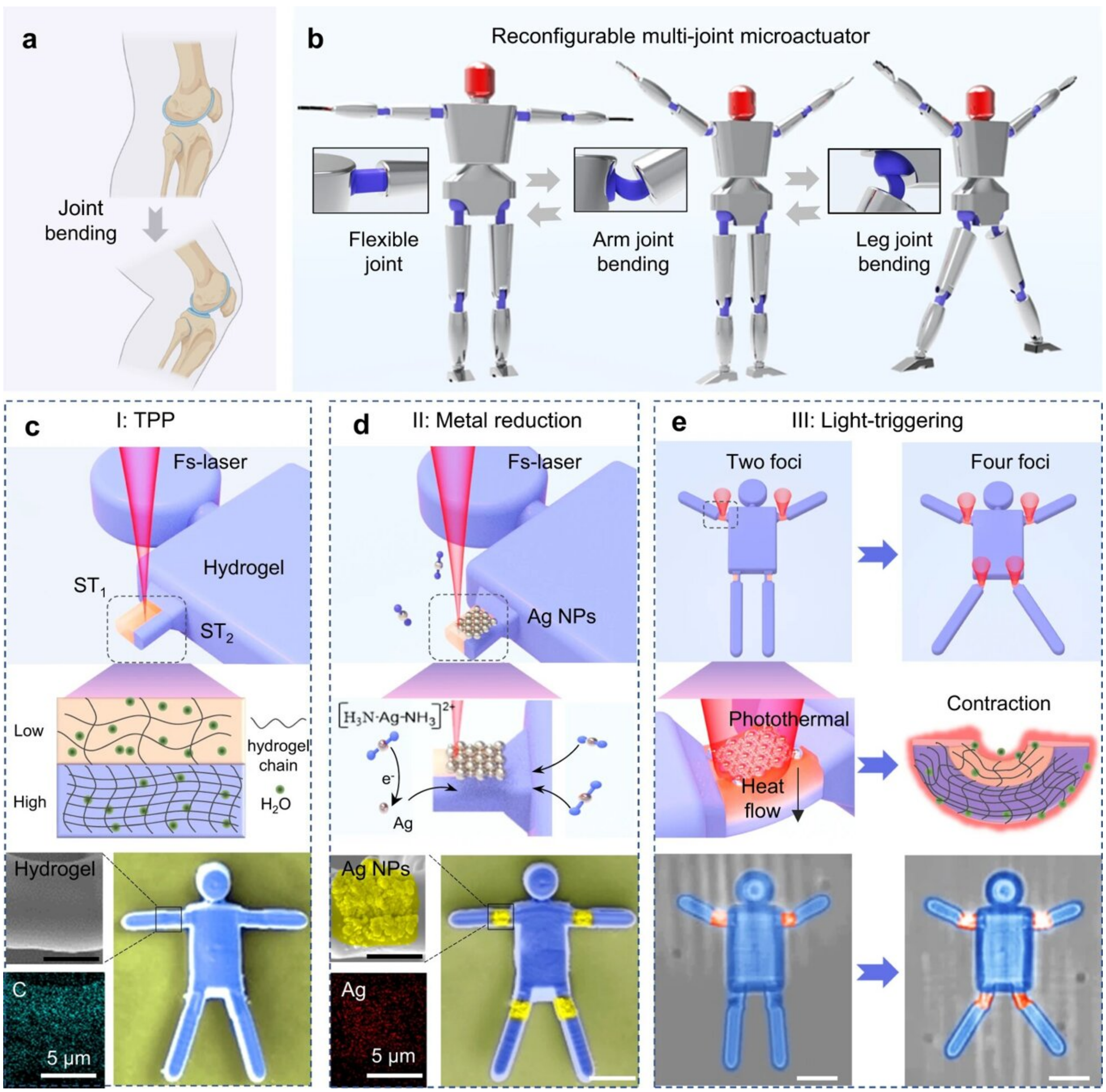

Design and Fabrication of light-triggered multi-joint microactuators (MJMAs) by two-in-one laser printing. **a** The human arm relies on joint bending to achieve hand raising. **b** The schematic diagram of a light-triggered humanoid MJMA showing multiple modalities. **c** Laser printing responsive hydrogel to construct the MJMA skeleton. The joint is composed of two parts with different cross-link densities, where orange and blue represent low and high cross-link densities, respectively. ST_1 = 1 ms and ST_2 = 3 ms are single-point scanning time during processing. **d** Laser reduction of Ag NPs for photothermal conversion, in which silver ammonium ions absorb photons and are reduced to Ag NPs. SEM images show the corresponding materials of hydrogel MJMAs (blue) and Ag NPs (yellow), respectively. **e** Two foci and four foci are modulated by the Gerchberg-Saxton algorithm to control the deformation of two and four joints, where the spatial position and intensity of the focal spot can be flexibly adjusted. When Ag NPs are irradiated by NIR light, a large amount of heat transfer from Ag NPs to hydrogel will be generated. The parts of the hydrogel with low cross-link density contract more than the part of the hydrogel with high cross-link density, thus causing directional bending of the hydrogel joint. All scale bars are 20 μm. Credit: *Nature Communications* (2023). DOI: 10.1038/s41467-023-40038-x

A research team led by Prof. Wu Dong from the University of Science and Technology of China (USTC) of the Chinese Academy of Sciences (CAS) proposed a femtosecond laser 2-in-1 writing multi-material processing strategy to fabricate micromachined joints composed of temperature-sensitive hydrogels and metal nanoparticles, and developed multi-jointed humanoid micromachines with multiple deformation modes (>10). The results were published in *Nature Communications*.

In recent years, femtosecond laser two-photon polymerization, as a true three-dimensional fabrication technique with nanoscale precision, has been widely employed to produce various functional microstructures. These microstructures have shown great potential in areas such as micro-nano optics, microsensors, and microelectromechanical systems. However, the challenge remains in leveraging femtosecond lasers for multi-material processing and further constructing micro-nano mechanics with multi-modalities.

In this study, the femtosecond laser dual-function fabrication strategy involves using asymmetric two-photon polymerization to create hydrogel joints and locally depositing silver nanoparticles (Ag NPs) via laser reduction within the joints. This asymmetric light-polymerization technique induces anisotropy in cross-linking density within specific areas of the hydrogel micro-joints, ultimately enabling directional and angular-controllable bending deformations.

The in-situ laser reduction deposition allows for precise fabrication of silver nanoparticles on the hydrogel joints. These nanoparticles exhibit strong photothermal conversion effects, enabling the multi-joint micromachinery to showcase ultra-fast response times (30 ms) and extremely low driving power (

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