

Supporting Information

Experimental Sections

Materials

Mono-dispersed silica microspheres (nominal diameter of 5 μm) were supplied by Micromod Partikeltechnologie GmbH. The CoFe_2O_4 and BaTiO_3 ceramic targets were supplied by Wuxi Kai-Star Electro-optical Materials Co., Ltd. The other chemicals were purchased from Sigma-Aldrich. All the chemicals were used without further purification. 500 μm -thick silicon wafers $\langle 100 \rangle$ were used as substrates in the experiments.

Formation of monolayer of silica sphere

The substrates were cleaned by immersing them into a Piranha solution containing 30% H_2O_2 and 70% H_2SO_4 for 15 min, and then rinsing them with deionized water.

Self-assembled monolayers of silica microspheres were obtained by dipping silicon substrates into a well dispersed silica microsphere suspension. Before dipping, the suspension was dispersed in an ultrasonic bath. During the coating process, the substrate was vertically dipped into the suspension for a few minutes and withdrawn at a speed of 2000 $\mu\text{m}/\text{s}$ at room temperature.

Functionalization of the microsphere by sputtering CoFe_2O_4 and BaTiO_3 layers

The silica spheres monolayer was transferred together with the silicon substrate to the vacuum chamber (base pressure: 8×10^{-7} Pa) of PVD sputtering machine (PVD Products). The sputtering was carried out after the substrate temperature achieved 600 $^\circ\text{C}$. CoFe_2O_4 was radio frequency-sputtered under pure Ar atmosphere at a pressure of 10 mTorr and a power of 100 W. BaTiO_3 was sputtered at a power of 120 W, and the pressure was set to 20 mTorr.

The atmosphere was a mixture of Ar and O₂ with a ratio of 4:1. A bare silicon wafer was also prepared for reference.

Nobel metal reduction experiments

AgNO₃, HAuCl₄, and K₂PtCl₆ salts were dissolved in DI water respectively. The final metal concentration in each solution was 50 mM. The magnetoelectric chips were put in the solution, and then located between the pole-pieces of a custom-built electromagnet. The magnetic field for triggering the magnetoelectrochemical reactions was a DC field (80 mT) superimposed with an AC field (5 mT, 100 Hz). 3 sets of control samples were also prepared for comparison: two of them were simply CoFe₂O₄ or BaTiO₃ coated silicon chips placed in the solution and subject to magnetic fields, and the third one was CoFe₂O₄/BaTiO₃ bilayer composite films placed in the solution in the absence of magnetic fields. All the experiments were carried out in darkness.

Magnetic actuation of the JMPs

Before the magnetic actuation, the as-fabricated JMPs were suspended in DI water after a 15 min sonication step. Afterwards, the JMP suspension was transferred into a small container, and placed under a magnetic control system, which includes an eight-coil Magnetic Field Generator (MFG) commercialized by MagnetbotiX AG (www.magnebotix.com) and an inverted optical microscope (Olympus IX-81) with a camera for visual feedback. The system is capable of 5-DOF wireless control of magnetic micro- and nanostructures (3-DOF position, 2-DOF pointing orientation), within a spherical workspace with a diameter of approximately 10 mm. This allows for magnetic fields and field gradients up to 20 mT and 1 T/m respectively at frequencies up to 4 kHz.

Characterization

SEM was taken with a Zeiss NVision 55 scanning electron microscope (SEM). For EDX mapping, a FEI Quanta 200 equipped with an Energy-dispersive X-ray analysis detector was employed. XRD patterns were acquired on a Bruker D8 Advance X-ray diffractometer equipped a Cu target with the wavelength of 1.542Å. Magnetic measurements were obtained using a vibrating sample magnetometer (VSM EZ9, Microsense). The Piezoresponse force microscopy (PFM) investigations were performed on a commercial atomic force microscope (NT-MDT Ntegra Prima). Pt-coated Si probes, i.e. PPP-CONTAu (spring constant $k \sim 0.2 \text{ N m}^{-1}$), were used, and the imaging contact force set-points were carefully controlled. For domain imaging, AC signal (amplitude $V_{AC} = 1 \text{ V}$) was applied through the tip to excite surface oscillations.

Discussion on piezoelectrochemical reactions

Some authors claim that only straining piezoelectric materials such as ZnO, chemical reactions such as dye degradation cannot be induced.¹ Our result is different from theirs in two aspects. First, the piezoelectric material used in this work is BaTiO₃ whose piezoelectric coefficient is higher than ZnO in their study. A higher piezoelectric coefficient means a better efficiency in inducing chemical reactions. Second, while, in general, reduction of noble metal is usually a spontaneous process ($\Delta G < 0$), dye degradation processes are not; and the energy barrier for cleaving covalent bonds in organic compounds is much higher than the energy required for electronic transfer in noble metal reduction. Probably these two facts are the reasons why dye degradation was not observed by simply straining the piezoelectric ZnO nanowires. Interestingly, other researchers observed indeed that chemical reactions such as water splitting or dye degradation can be induced by simply straining ferroelectric microfibers made of BaTiO₃ and PZT, or even piezoelectric microfibers of ZnO.^{2,3}

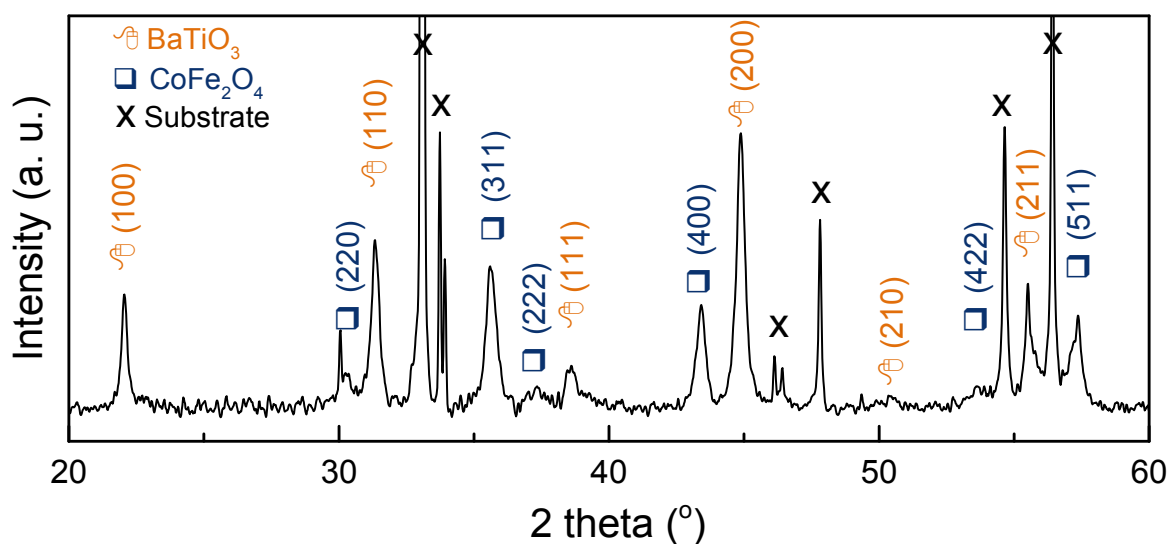


Figure S1 X-ray diffraction pattern of CoFe₂O₄-BaTiO₃ coated Janus microparticles on silicon substrate. The assignment of the peaks corresponds to JCPDS No.22-1086 (CoFe₂O₄) and JCPDS No.79-2264 (BaTiO₃).

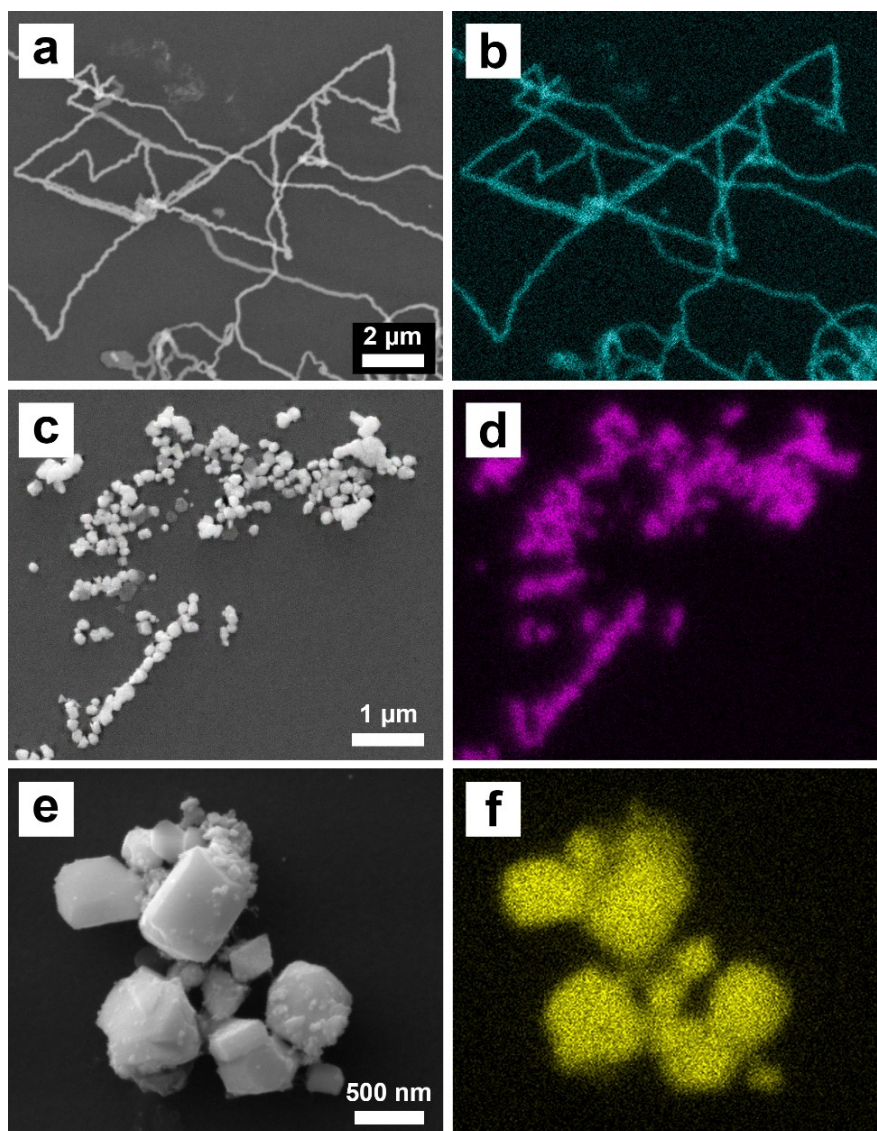


Figure S2 SEM images (a, c, e) of noble metal nanostructures on the surface of CoFe_2O_4 - BaTiO_3 thin film after reduction experiments. The corresponding element distribution EDX maps (b, d, f) confirm the composition of the nanoparticles.

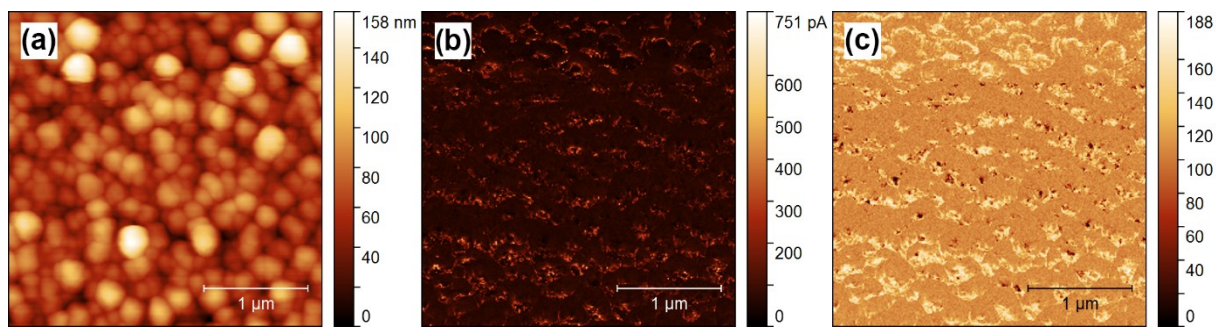


Figure S3 The morphology (a) and its corresponding amplitude (b) and phase (c) images of piezoelectric force response of $\text{CoFe}_2\text{O}_4\text{-BaTiO}_3$ on silicon substrate.

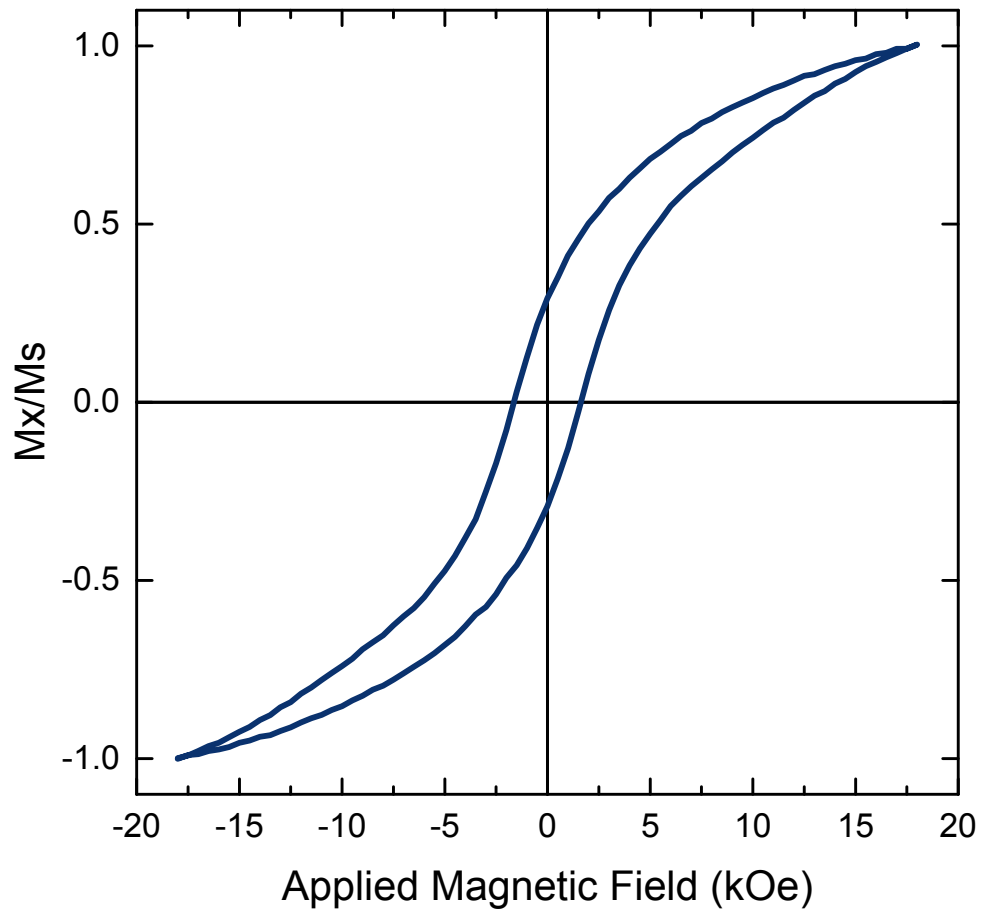


Figure S4 Magnetic loop of CoFe₂O₄-BaTiO₃ ME Janus particles.

References

1. X. Xue, W. Zang, P. Deng, Q. Wang, L. Xing, Y. Zhang and Z. L. Wang, *Nano Energy*, 2015, **13**, 414-422.
2. K.-S. Hong, H. Xu, H. Konishi and X. Li, *J. Phys. Chem. C*, 2012, **116**, 13045-13051.
3. H. Lin, Z. Wu, Y. Jia, W. Li, R.-K. Zheng and H. Luo, *Appl. Phys. Lett.*, 2014, **104**, 162907.