Electronic Supplementary Information (ESI)

Magnetostrictive-Piezocatalytic $CoFe_2O_4$@UiO-66 Nanohybrid and its Potential for Deep-seated Tumor Treatment

Qian Yu, [a] Meiyu Li,[a] Jiaojiao Zhang,[b] Hong Liu,[b] Long Zhang,[b] Shun Li,[b] Dengfeng Ge[c]* and Jianming Zhang,[b]**

[a.] School of Life Sciences, Jiangsu University, 301 Xuefu Rd, Zhenjiang, China, 212013.
[b.] School of Chemistry and Chemical Engineering, 301 Xuefu Rd, Zhenjiang, China, 212013.
[c.] Shengli Oilfield Central Hospital, 31 Ji'nan Rd, Dongying, China.

Experimental details:

Materials: Iron (III) acetylacetonate ($Fe(acac)_3$), cobalt (II) acetylacetonate ($Co(acac)_2$), oleic acid and benzyl ether, 2,3-dimercaptosuccinic acid (DMSA), $ZrCl_4$, 2-aminoterephthalic acid ($BDC\text{-}NH_2$) were purchased from Aladdin Reagents. 5,5-Dimethyl-1-pyrroline N-Oxide (DMPO) was obtained from DOJINDO Co. Ltd. N-dimethylformamide (DMF), hexane, toluene and ethanol were obtained from Sinopharm Chemical Reagent. All chemicals were analytical grade and used as received without further purification. All aqueous solutions were freshly prepared by using deionized water. PC9 (cancer) and 16HBE9 cells were obtained from Shanghai EK-Bioscience Biotechnology Co., Ltd.

Synthesis of $CoFe_2O_4$ (CFO) NPs:[1] Typically, 1.2 mmol of $Fe(acac)_3$, 0.6 mmol of $Co(acac)_2$, 2.5 mL of oleic acid and 20 mL of benzyl ether were mechanically mixed in a flask. This mixture was heated at 100 ^oC under N_2 for 30 min; the reaction temperature was subsequently increased to 280 ^oC with a heating rate of 5 ^oC/min and kept for 90 min. After cooling to room temperature, 20 mL of ethanol was added to the solution to precipitate black products at bottom. The precipitate was collected and washed with ethanol for 3 times and then dried in vacuum oven at 60 ^oC overnight.
A ligand-exchange manipulation was then conducted to the NPs for phase transfer. To do so, 10 mg of CFO NPs were dissolved in 1 mL of toluene, which was then mixed with 10 mg of DMSA dissolved in 1 mL of DMSO. This mixture was sonicated for 30 min, and then stirred mechanically at room temperature for 12 h. The NPs was collected by centrifugation and redispersed in water.

Synthesis of CFO@UiO-66 NPs:[2] In a typical process, 100 mg of CFO NPs were dispersed in 30 mL of DMF under mechanical stirring. Ten (10) mL of DMF solution with $ZrCl_4$ concentration of 1 M was then injected to the CFO solution. This mixture was continuously stirred at 60 ^oC for 30 min, followed by an addition of 1 mmol of $BDC\text{-}NH_2$. The solution temperature was increased to 120 ^oC and kept isothermal for 2 h. Once the solution is cooled to room temperature, the NPs was separated by centrifuge and washed using DMF/centrifugation for three times. The purified NPs were redispersed in methanol for 3 days and then recollected by centrifugation. The final product of CFO@UiO-66 was dried in vacuum oven at 60 ^oC overnight for further characterization and catalysis test.
The UiO-66 NPs were synthesized in the similar way without using CFO NPs.

AC-MF catalysis: Typically, 100 mg of the NPs was dispersed in 50 mL of 1×10^{-5} M of RhB aqueous solution in a beaker under mechanical stirring in darkness for ~1 h to reach an equilibrium adsorption for dye molecules. The solution was then placed in a Helmholtz coil under mechanical stirring with a glass stirrer paddle at room temperature. The Helmholtz coil was connected to a 5000 W AC power supply, and the AC-MF was set with a flux density (B) of ~ 80 Gs and a frequency (f) of ~ 1100 Hz. At regular intervals, aliquots were removed and analyzed by UV-Visible spectroscopy.
The production of H_2O_2 test was performed similarly, except that RhB was excluded. The H_2O_2 concentration was quantified using the classic Iodometry method with UV-Visible spectroscopy.

Electrochemical current test: In a typical procedure, 5 mg of the NPs was added in 5 mL of ethanol with sonication to form a uniform suspension. This solution was spin coated on an ITO substrate (1.0 × 1.0 cm) and dried in air to form the working electrode. Ag/AgCl electrode and Pt wire, as reference and counter electrodes, respectively, were assembled with the working electrode into a standard 3-electrode cell for current generation test. The electrolyte was prepared by adjusting the pH of the degassed Na_2SO_4 aqueous solution (0.5 M) to be ~ 2.6 for cell test. The cell was placed in the Helmholtz coil with a flux

density (B) of ~ 80 Gs and a frequency (f) of ~ 1100 Hz, and the current signal was recorded using a CHI-760E electrochemical station.

In Vitro Cytotoxicity: PC9 and 16HBE9 cells were selected as examples of cancer and normal cells, respectively, to evaluate the cytotoxicity of NPs. Cells in the log phase of growth were seeded in 96-well plates at the density of 7×10^3 cells per well and incubated 24 h for cell attachment. NPs solution was then diluted appropriately in fresh culture media and added to the wells (200 μL). After 24 h of continuous exposure to various concentrations of NPs, the culture media were changed back to fresh culture media to remove free NPs in the solution, and cell viability was investigated by standard WST assays.

In vitro treatment to cancer cells under AC-MF: First, PC9 cells were incubated with 1200 ppm of NPs for 24 h. After removing free NPs, the culture dish was embedded in embedded in pork epithelial tissues of different thicknesses as a sandwich-like structure. The tissue protected dish was then placed in the AC-MF field for treatment of 10 min, and then the cell viability was counted.
For the confocal microscope observation of stained cells, 15 μL of Calcein-AM and 15 μL of PI dispersed in 7.5 mL of PBS were used to replace the cell culture media and stained live (green) and dead (red) cells after varied treatments. After 15 min of staining, the cells were washed three times with PBS and observed by confocal microscope.

Characterization: NPs were observed with ThermoFisher Talos 200X for TEM and Apreo 2S for SEM. UV–vis spectra were recorded on a Shimazu UV-3600i Plus spectrometer. XRD was inferred from Rigaku Rotaflex D/MAX-2500 with Cu Kα radiation (λ=1.54178 Å). ESR spectroscopy of the radical spin-trapped by DMPO was recorded using a A300-10/12 ESR Spectrometer. DMPO was mixed with NP aqueous solution in advance for field treatment and then extracted for ESR measurement. Magnetic property was measured using a LakeShore7404 Vibrating Sample Magnetometer (VSM) at room temperature. PFM measurements were performed using an Oxford Instrument MFP-3D Origin+ atomic force microscope. An Olympus IX-73 Confocal microscope was used for stained cell observation. AC-MF generator was customized by Yingpu (Changchun) Magnetoelectric Co. Ltd. AC-MF intensity was measured using a CH-3600 gauss meter (Beijing Cuihaijiacheng Magnetoelectric Technology Co., Ltd).

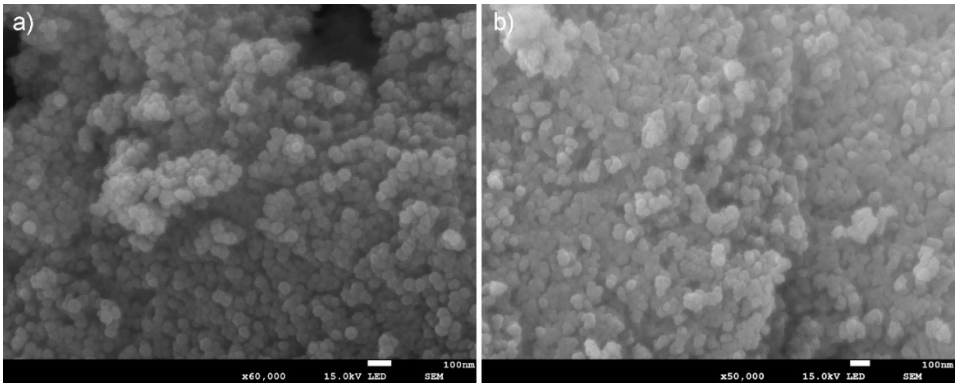

Fig. S1 SEM image of the CFO NPs before (a) and after UiO-66 encapsulation (b).

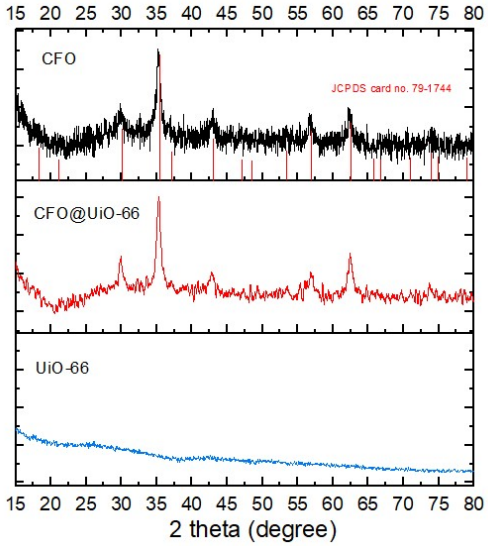

Fig. S2 XRD patterns for CFO, CFO@UiO-66 and UiO-66 NPs.

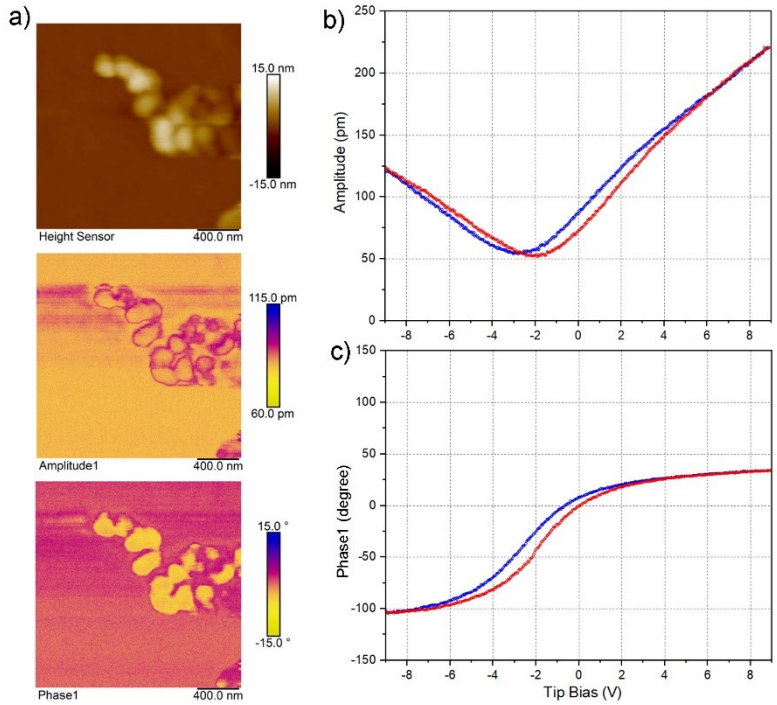

Fig. S3. (a) Topographic, amplitude and phase images of CFO@UiO-66 nanohybrids. (b) The corresponding amplitude butterfly loops and (c) phase hysteresis of the nanohybrid.

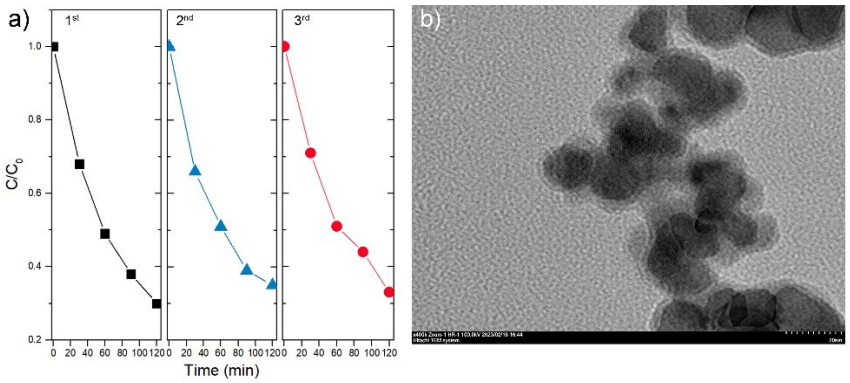

Fig. S4. (a) Cycling test of catalytic degradation of RhB. (b) TEM image of the CFO@UiO-66 sample after cycling test.

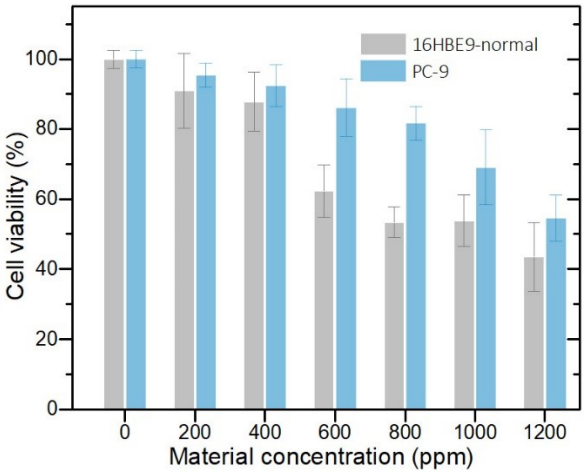

Fig. S5 Viabilities of the 16HBE9 and PC9 cells evaluated by WST assay after incubating the cells with CFO NPs of different concentrations for 24 h.

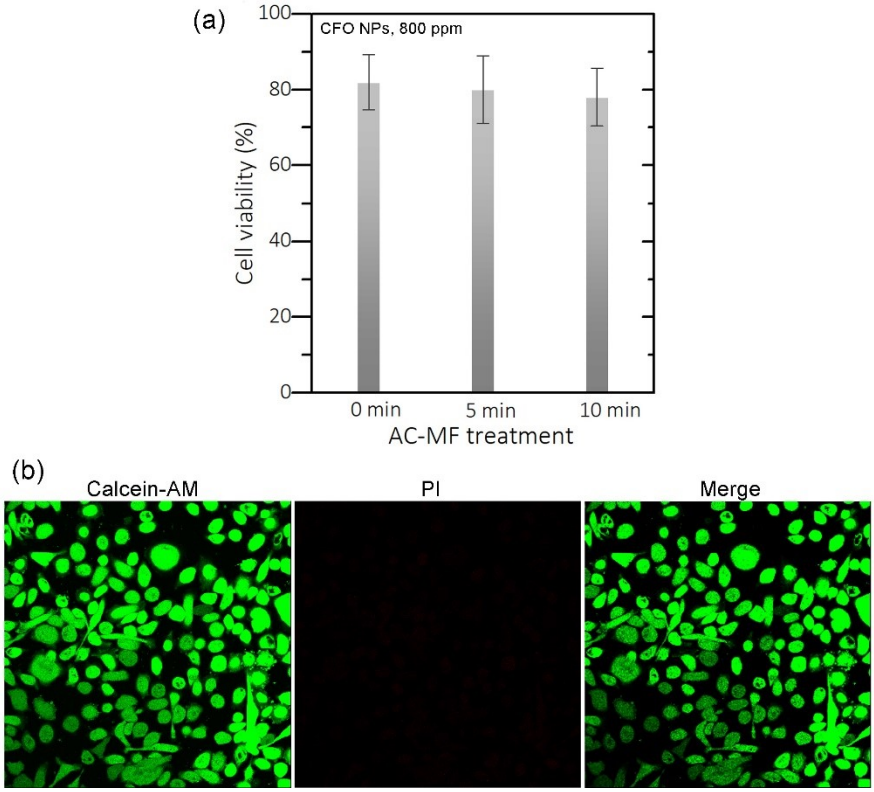

Fig. S6. (a) Viabilities of the PC9 cells evaluated by WST assay after incubating the cells with CFO NPs (800 ppm) before (0 min) and after (5, 10 min) MF treatment. (b) Confocal microscopic images of CFO incubated PC9 cells using different stains of Calcein-AM and PI under AC-MF treatment.

References

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2 D. Li, S.-H. Yu and H.-L. Jiang, *Adv. Mater.*, 2018, **30**, 1707377.