

## Electronic Supplementary Information (ESI)

The positively charge collective oscillations induced high-efficiency A $\beta$ 1-42 fibrils degradation by Au@Cu<sub>2-x</sub>S core/shell nanocrystals

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## Experimental section

**Chemical and Reagents.** Tetrachloroauric (III) acid tetrahydrate ( $\text{HAuCl}_4 \cdot 4\text{H}_2\text{O}$ , 99.9%), cetyltrimethylammonium bromide (CTAB, >99.0%), Benzyldimethylhexadecylammonium chloride (BDAC, 97%), sodium borohydride ( $\text{NaBH}_4$ ,  $\geq 98\%$ ), silver nitrate ( $\text{AgNO}_3$ , 99+%), ascorbic acid (A.A, 99.7+%), sodium hydroxide ( $\text{NaOH}$ , 96%), sublimed sulfur (99.5%), cadmium nitrate [ $\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$ , 99.999%], tributylphosphine (TBP, 95%), tetraacetic acid copper hexafluorophosphate [ $\text{Cu}(\text{CH}_3\text{CN})_4\text{PF}_6$ , 99%], ethylene glycol (EG,  $\geq 99.5\%$ ), hexafluoroisopropanol (HFIP, 99%), dimethyl sulfoxide (DMSO, 98%) and other reagents were purchased from Beijing Chemical Factory. All reagents are used without further purification.

**The synthesis of  $\text{Au}@ \text{Cu}_{2-x}\text{S}$  NRs.** Au NRs with controlled aspect ratio (AR) were synthesized by seed-mediated growth reported by El-sayed<sup>1</sup> with slight modification. Au NRs were redispersed in 10 mL deionized water and mixed with 0.36 g CTAB. Then, 0.2 mL 10 mM  $\text{AgNO}_3$ , 5 mL 0.1 M A.A and 5 mL 0.1 M  $\text{NaOH}$  aqueous solution were added and stirred several minutes until the color converted to green. The resulting solution was kept at 30 °C for 2 h. Then, 100  $\mu\text{L}$  as-prepared sulfur precursor (32 mg of sulfur powder was mixed with 11.7 mL 0.05 M  $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$  aqueous solution in a 50 mL plastic tube followed ultrasonic until bright yellow and transferred to a 20 mL autoclave at 80 °C for 12 hours) was added into the  $\text{Au}@ \text{Ag}$  NRs colloids solution, stirred for 5 min and redispersed in 10 mL of 0.05 M CTAB solution. Then, 1 mL 0.03 g/mL  $\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$  methanol solution and 50  $\mu\text{L}$  TBP were added to the  $\text{Au}@ \text{Ag}_2\text{S}$  suspension in a 50 mL plastic tube and kept at 60 °C for 2 hours. The  $\text{Au}@ \text{CdS}$  NRs

colloidal solution was separated by centrifugation (7000 rpm 10 min) and redispersed in 10 mL EG. Continuously, 0.2 mL 5 mg/mL  $\text{Cu}(\text{CH}_3\text{CN})_4\text{PF}_6$  methanol solution was added, the color of mixture changed from blue to yellowish green rapidly. The product was washed quickly by deionized water and redispersed in 10 mL EG for characterization.

**Instrumentation.** Low-resolution transmission electron microscopy (LRTEM) images were obtained on a HITACHI H-7650 electron microscopy operating at 60 kV. High-resolution transmission electron microscopy (HRTEM) images, elemental mapping and EDS spectra were performed on an FEI Tecnai G2 F30 S-Twin operating at 200 kV equipped with X-ray energy-dispersive spectroscopy detector. The X-ray diffraction (XRD) was selected using a Bruker D8 multiply crystals X-ray diffractometer ( $5^\circ$  per min). The ultraviolet-visible-near-infrared (UV-Vis-NIR) spectra of samples were measured on a Shimadzu UV3600 UV-Vis spectrophotometer at room temperature (RT). Atomic force microscope (AFM) images were obtained by Dimension 3100 AFM (Bruker, USA) under tapping mode. And the tip is a commercial Si tip with a resonance frequency of 397.7 kHz. The TEM and XPS characterizations were supported by Beijing Zhongke-baice Technology Service Co., Ltd.

**Photothermal (PT) conversion characterizations.** As-prepared  $\text{Au}@\text{Cu}_{2-x}\text{S}$  NRs were separated from the EG by centrifugation (7000 rpm/10 min) and redispersed in water. 1 mL of  $\text{Au}@\text{Cu}_{2-x}\text{S}$  NRs was placed in a quartz cuvette and irradiated by 808 nm laser for 10 min. The power density was controlled at  $1 \text{ W}/\text{cm}^2$ .

**Fourier transformation infrared (FTIR) spectra investigations.** Infrared spectra

were recorded on a PerkinElmer Fourier transform infrared spectrometer at a resolution of  $4\text{ cm}^{-1}$ . FT-IR spectroscopic measurements were performed in the transmission mode with  $\text{BaF}_2$  windows. The solution was dropped onto the  $\text{BaF}_2$  surface followed by air dry prior to FT-IR measurements.

**Atomic force microscope (AFM).** During the study,  $\text{A}\beta 1\text{-}42$  was dissolved into hexafluoroisopropanol (HFIP). We selected samples with a concentration of  $50\ \mu\text{M}$  and placed it in a constant-temperature water bath, aged at  $37\ ^\circ\text{C}$  for two days.  $2\ \mu\text{L}$  of sample solution was taken during the experiment and dripped on the newly dissociated mica surface. After 5 minutes of adsorption, the participating liquid was aspirated and dried with dry  $\text{N}_2$  to perform AFM experiments.

**Cell activity characterizations.** We selected the human neuroblastoma cells for cell activity measurements. Firstly, the synthesized  $\text{Au}@\text{Cu}_{2-x}\text{S}$  NRs were transferred from EG to deionized water by centrifugation. We selected the same concentration gradient and procedures of samples ( $\text{Au}$  NRs and  $\text{Au}@\text{Cu}_{2-x}\text{S}$  NRs) to investigate cell activity. The cells were treated with only  $\text{A}\beta 1\text{-}42$ , different ratio of  $\text{A}\beta 1\text{-}42$  and  $\text{Au}@\text{Cu}_{2-x}\text{S}$  NRs or  $\text{Au}$  NRs. After irradiation for one day, we added the same cells for incubation and selected 3-(4, 5-Dimethylthiazol-2-yl)-2, 5-diphenyl tetrazoliumbromide (MTT) to detect the cell activity characterizations. Three parallel experiments were performed of the above samples under different environments.

**PT conversion efficiency ( $\eta$ ):**

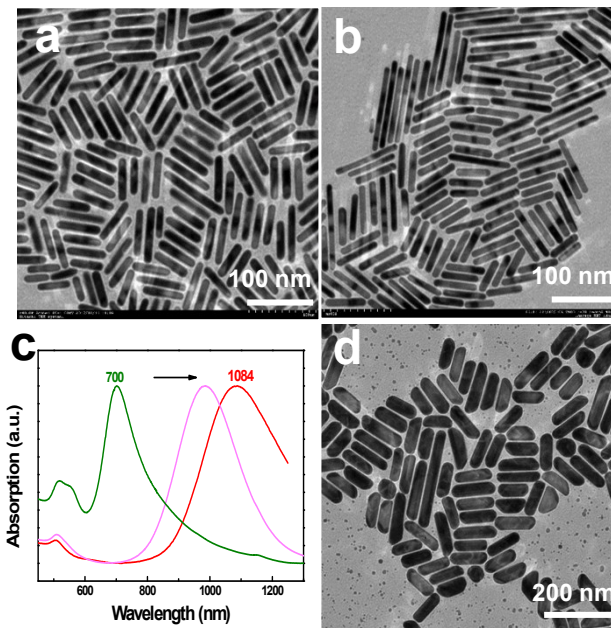
$$\eta = \frac{hS(T_{\max} - T_{\text{surr}}) - Q_{\text{dis}}}{I(1 - 10^{-A_{\text{laser}}})} \quad (1)$$

$$hS = \frac{\sum m_i C_{p,i}}{\tau_s}$$

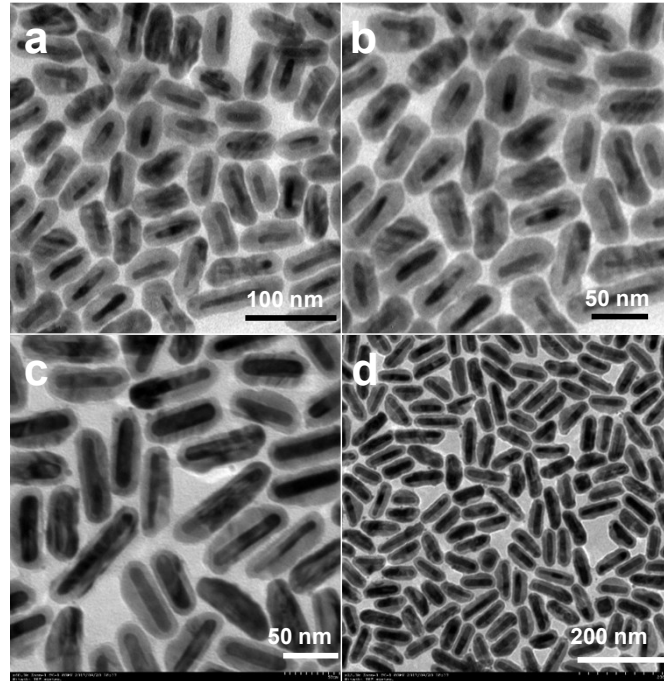
$$t = -\tau_s \ln \theta \quad (2)$$

$$\theta = \frac{T - T_{\text{surr}}}{T_{\max} - T_{\text{surr}}}$$

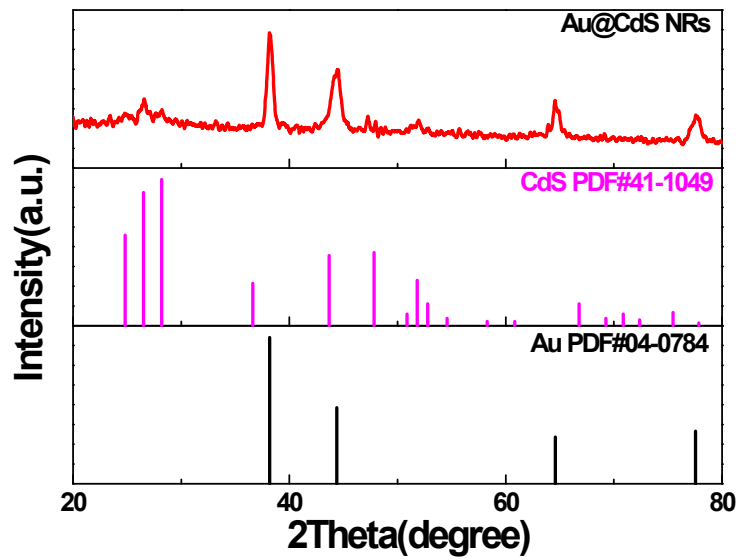
In the equation,  $h$  and  $S$  stands for heat transfer coefficient and area, respectively.  $T_{\max}$  is the highest temperature of system. And  $T_{\text{surr}}$  stands for the surrounding temperature.  $Q_{\text{dis}}$  is the baseline energy of the cell.  $I$  is the laser power 1 W.  $A_{\text{laser}}$  is the absorbance of sample collids at 808 nm.  $m$  and  $C_p$  are the mass and the heat capacity, respectively.  $t$  is cooling time after irradiation.



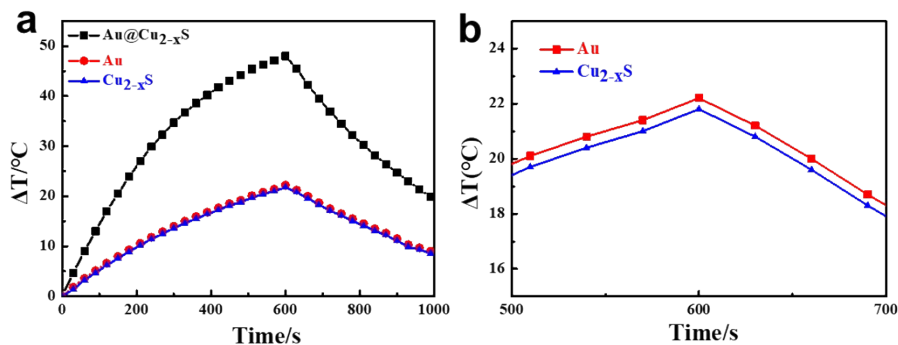
**Figure S1.** (a, b) TEM images of the synthesized Au NRs with different aspect ratio. (c) The UV-vis-NIR absorption spectra of different aspect ratio Au NRs. (d) TEM images of Au@Ag NRs.



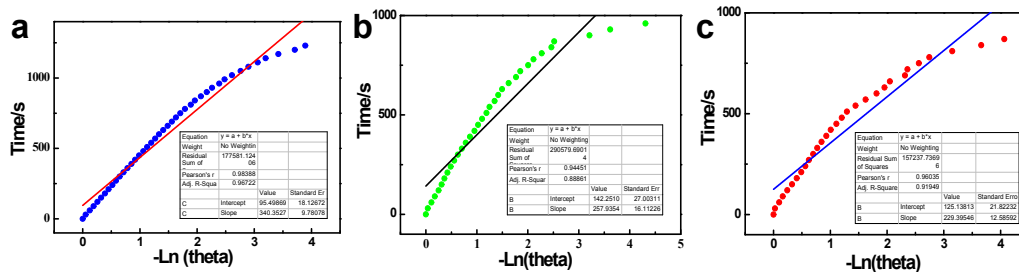
**Figure S2.** (a, b)TEM images of the synthesized Au@CdS NRs in water phase. (c, d) TEM images of Au@CdS NRs in EG.



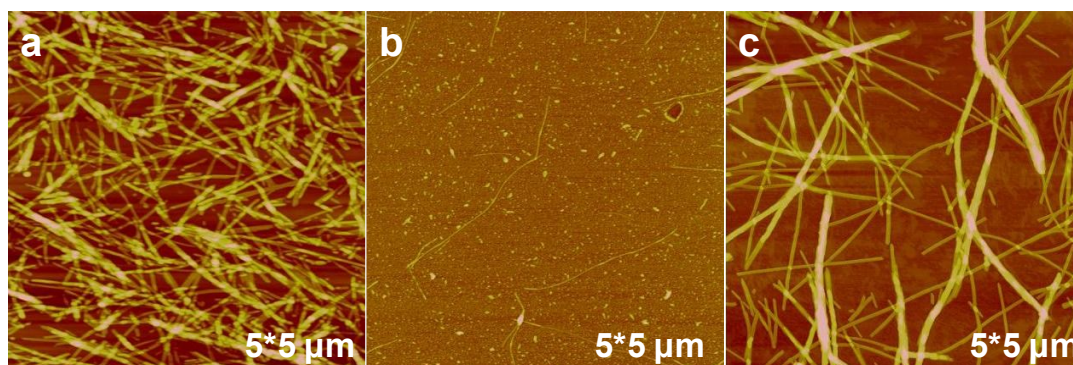
**Figure S3.** The XRD of Au@CdS NRs in EG phase.



**Figure S4.** (a) The change of temperature with same time of Au@Cu<sub>2-x</sub>S NRs, Au NRs and Cu<sub>2-x</sub>S aqueous solutions under 200 ppm and the enlarged image (b).



**Figure S5.** (a, b, c) Au@Cu<sub>2-x</sub>S NRs, Au NRs and Cu<sub>2-x</sub>S heat transfer time constant ( $\tau_{s1}$ ,  $\tau_{s2}$ ,  $\tau_{s3}$ ) of temperature change during cooling time after 808 nm laser irradiation.



**Figure S6.** (a, b, c) The AFM image of A $\beta$ 1-42 aggregates, added Au@Cu<sub>2-x</sub>S and Au NRs.

1. B. Nikoobakht and M. A. El-Sayed, *Chem. Mater.*, 2003, **15**, 1957-1962.

