ICMOL
INSTITUTE OF MOLECULAR SCIENCE

Harnessing Piezocatalysis for Water Remediation, Biomedicine and Beyond

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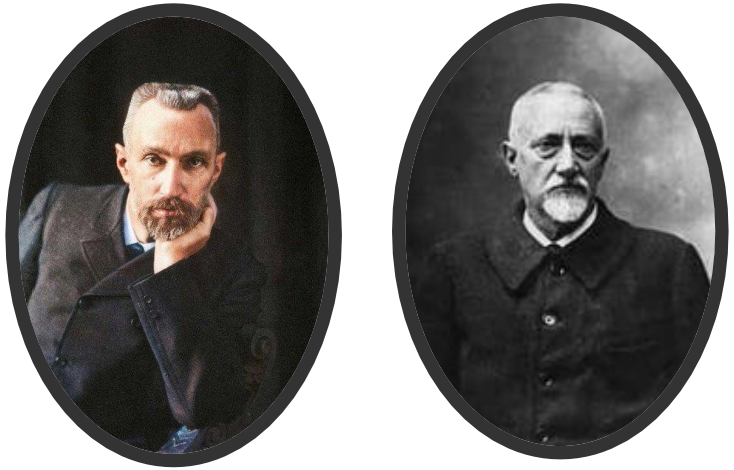
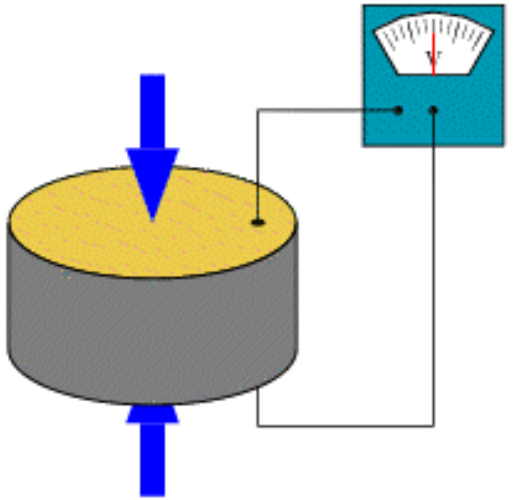
Piezoelectricity



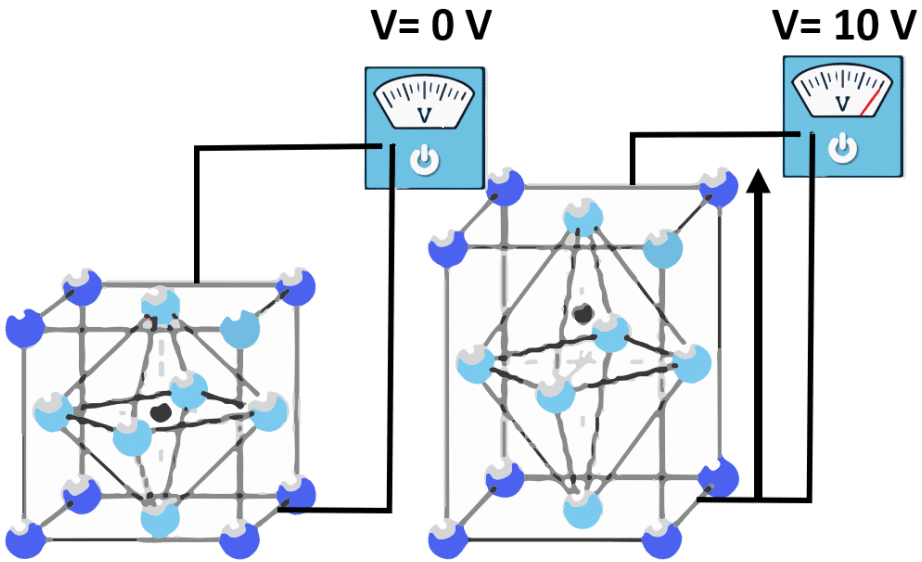
Pierre and Jacques Curie, 1880

When applying mechanical stress to certain crystals, electric charges and voltage were generated

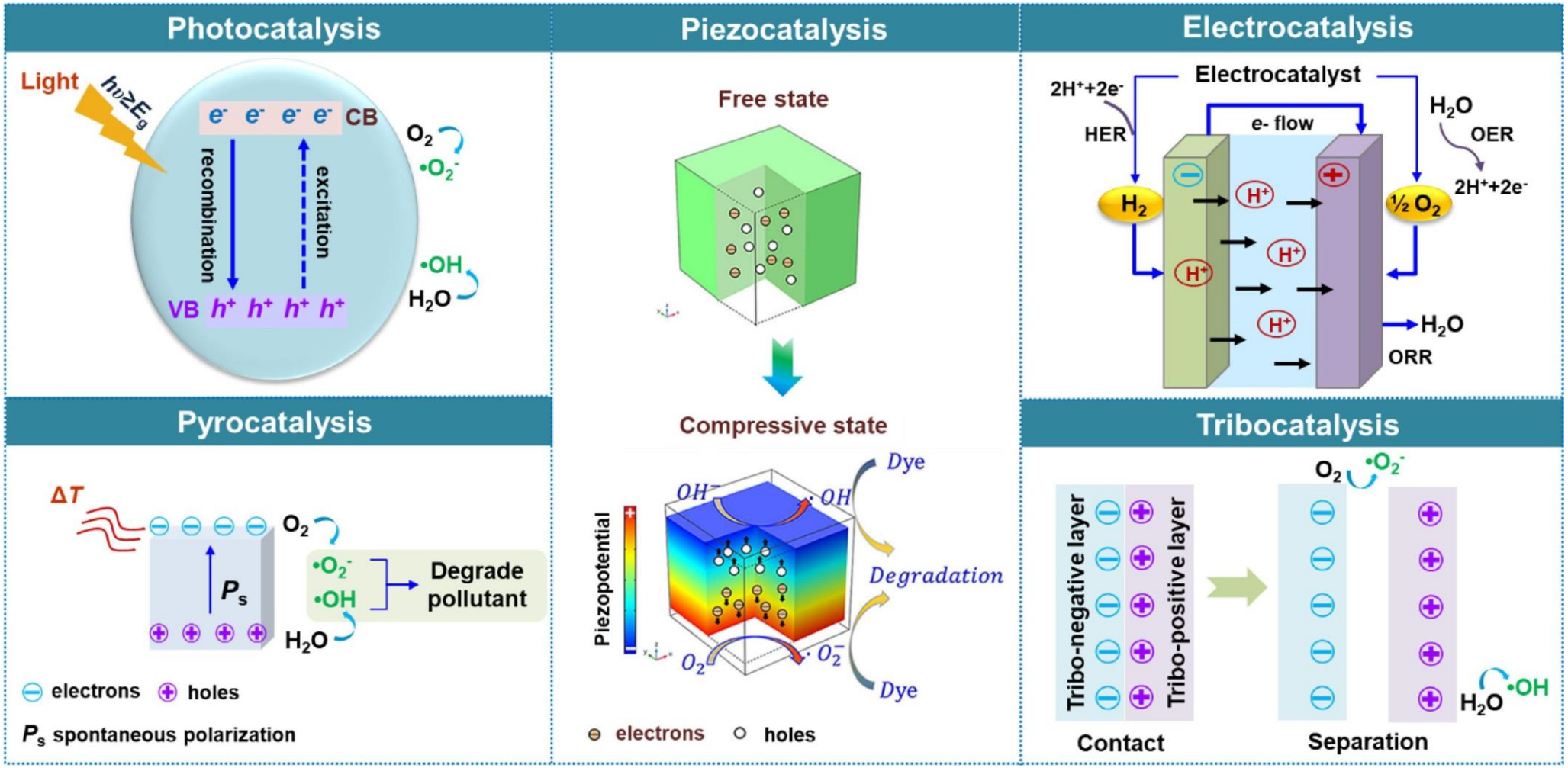


The piezoelectric effect is mostly linear and reversible

Piezoelectrics can convert mechanical energy into electrical energy, and vice versa

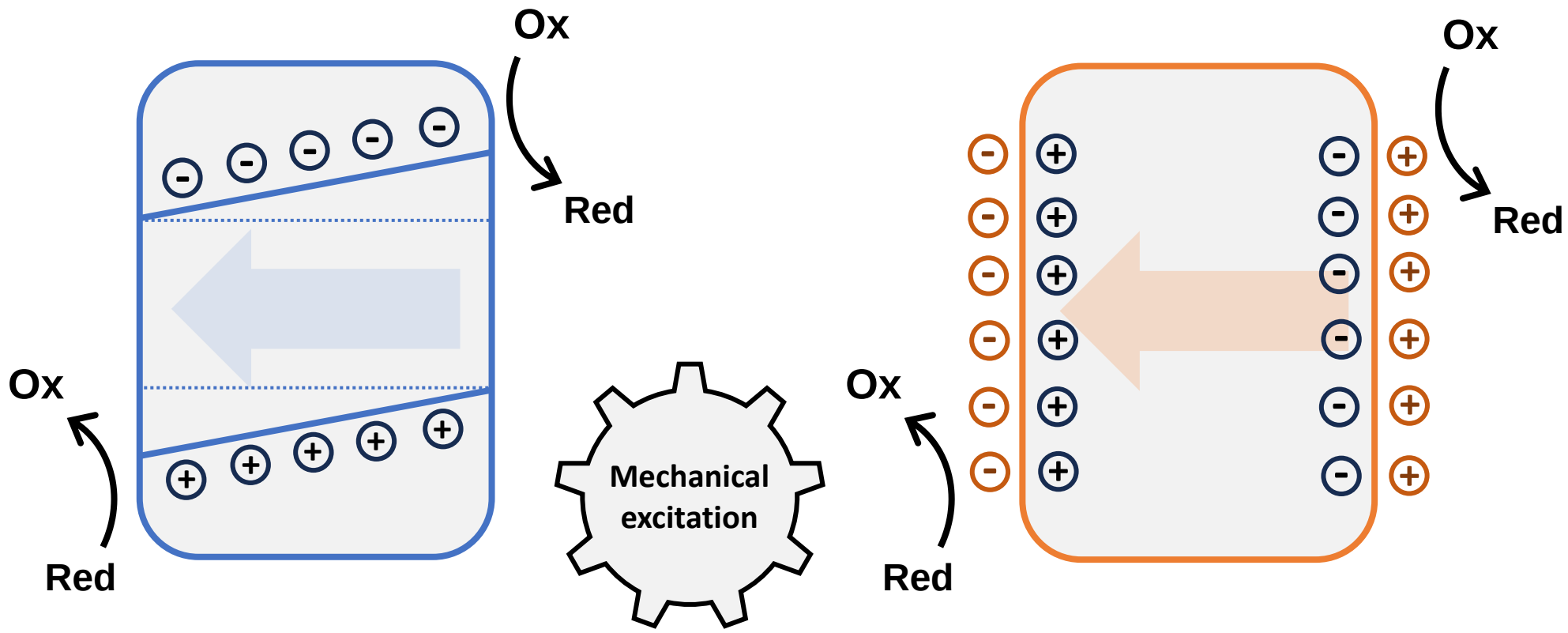


Piezocatalysis



Progress in Materials Science 138 (2023) 101161

Piezocatalysis



Energy Band Theory

Mechanical excitation induces polarization, shifting energy bands and promoting charge separation, leading to redox reactions.

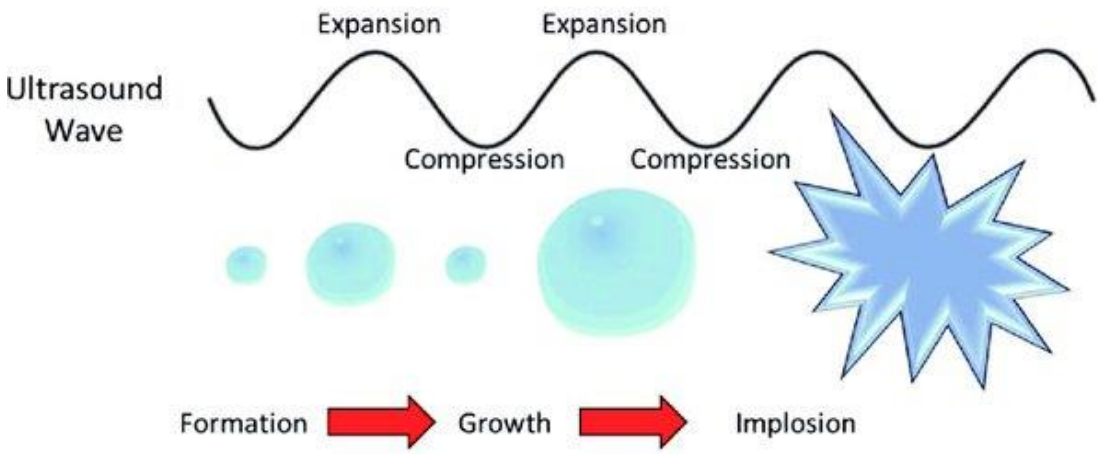
Screen Charge Effect

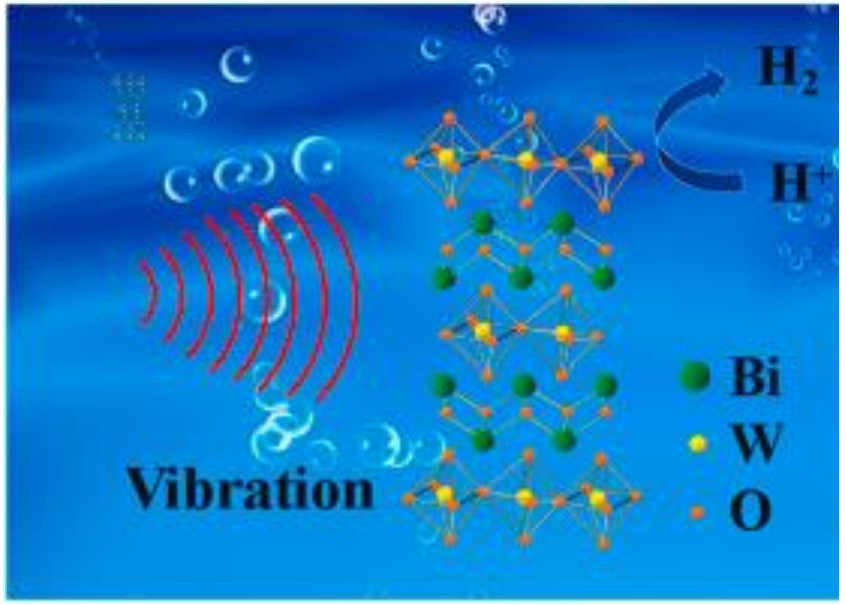
Polarization generates surface charges that attract opposite ions, facilitating redox reactions at the material interface.

Piezocatalysis

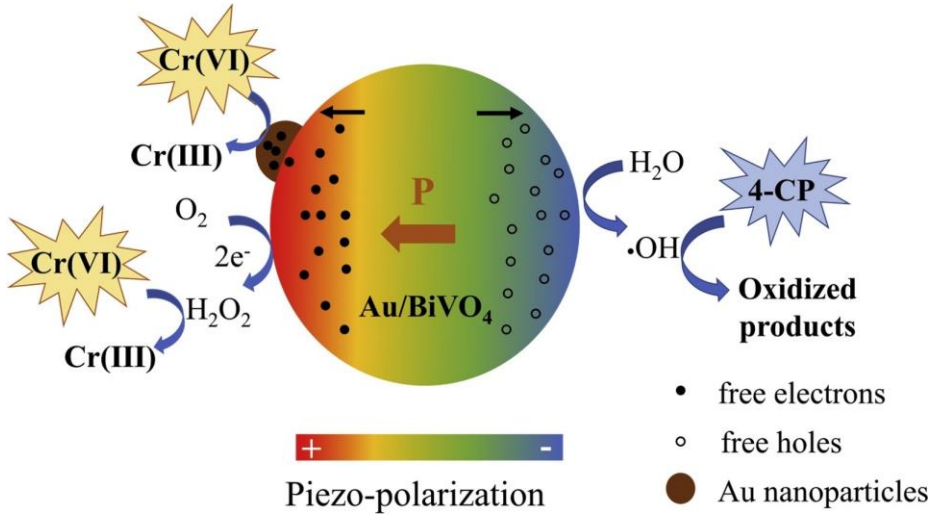
Ultrasound

- **Efficient mechanical activation**: Rapid and uniform mechanical stress.
- **No direct electric field needed**: No external electrical bias.
- **Better mass transfer**: Improves reactant access to catalyst surface.
- **Scalable and controllable**: Ultrasound parameters can be finely tuned.





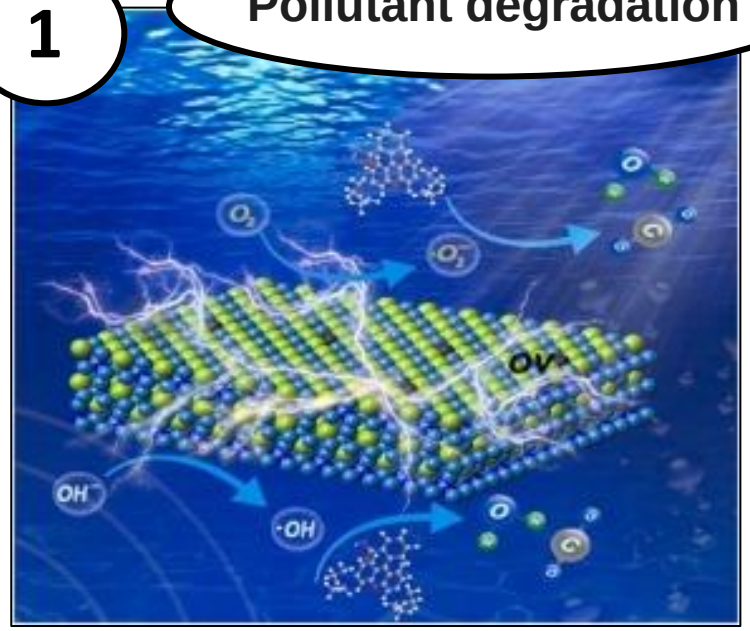
Nano Energy, 2020, *78*, 105351.



Applied Catalysis B: Environmental, 2019, *259*, 118084.

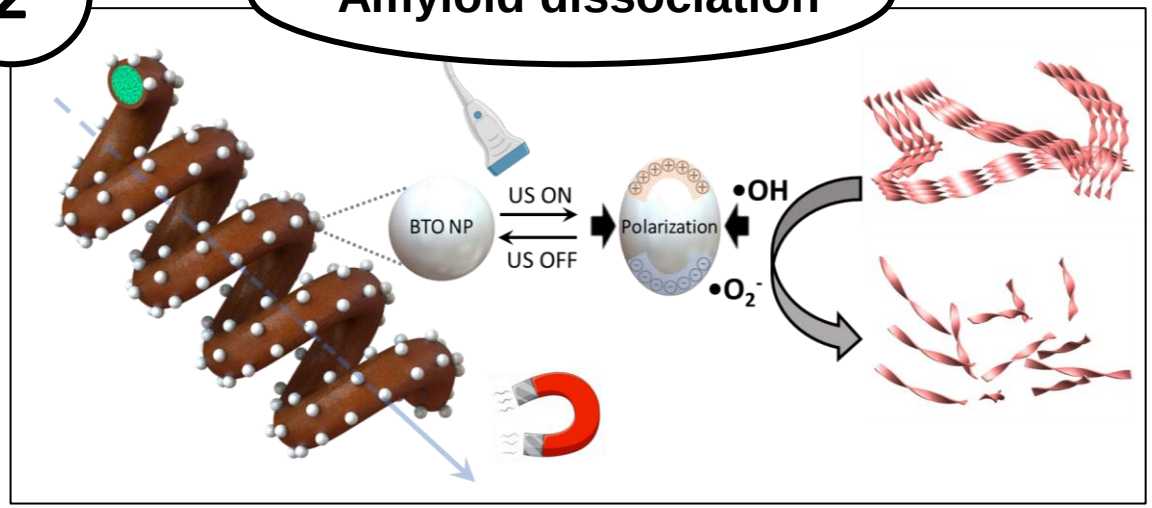
Outline

1 **Pollutant degradation**



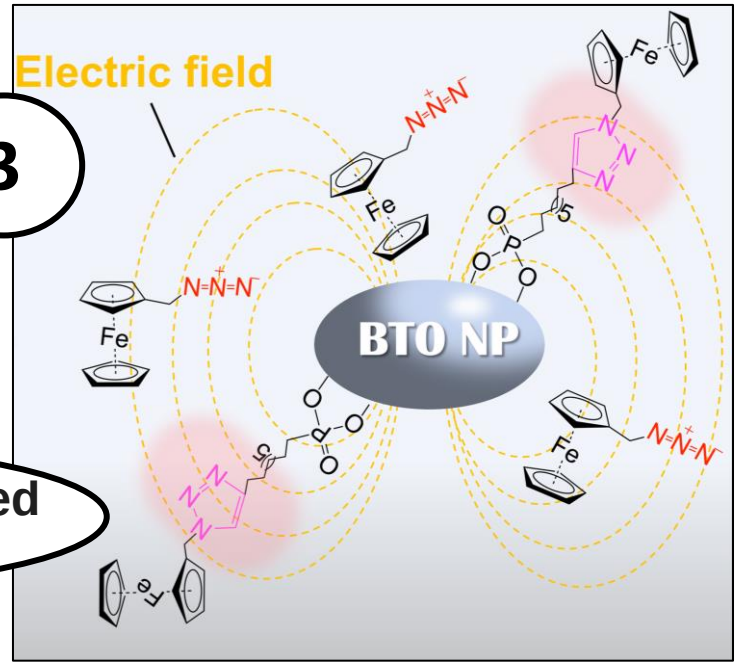
Nano Energy 2023 108, 108202

2 **Amyloid dissociation**



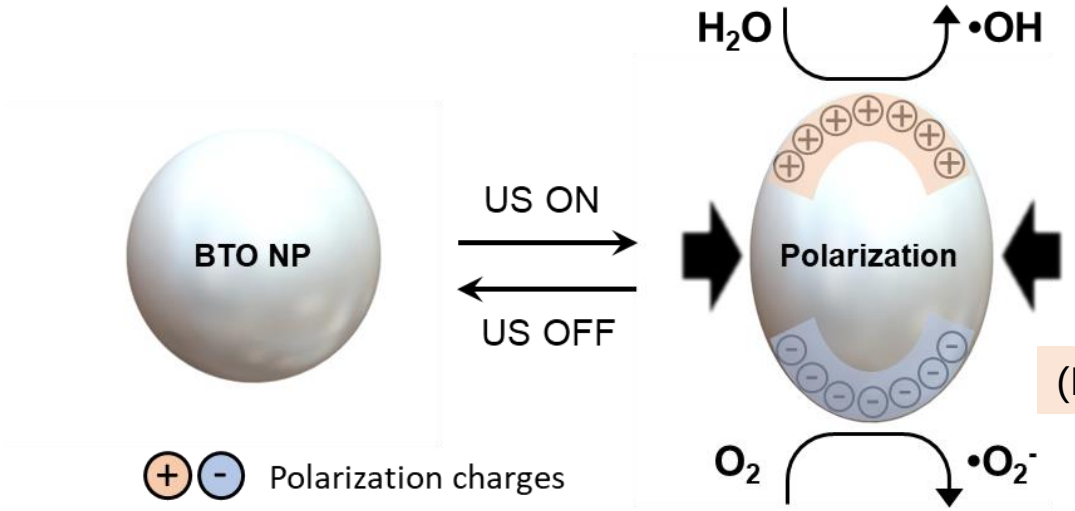
Nanoscale, 2023, 15 (36), 14800-14808

3 **Piezoelectric-assisted synthesis**



J. Am. Chem. Soc. 2025, 147, 10, 8289–8299

Piezocatalysis for water remediation



(In water)

Organic pollutants

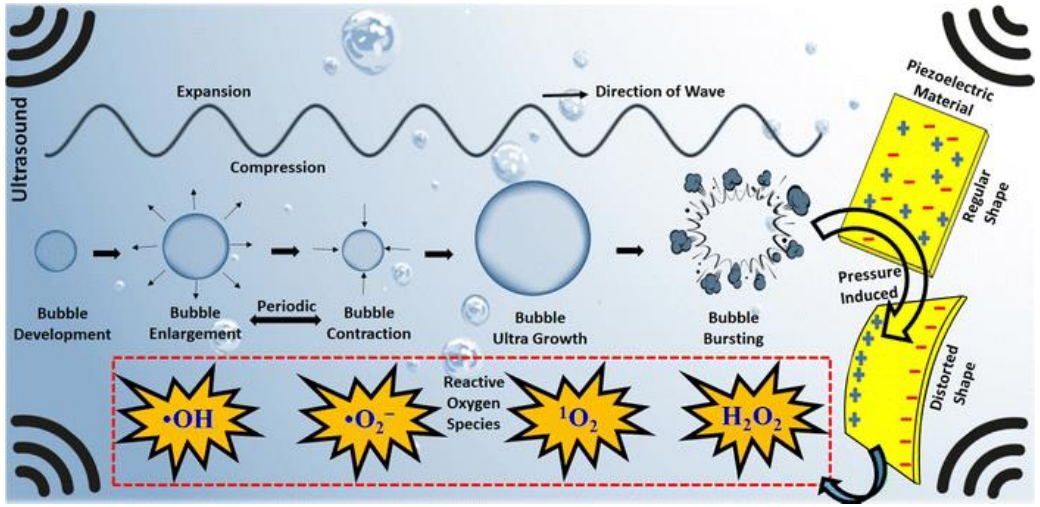
degradation

CO_2, H_2O, NO_3^-, HPO_4^{2-}

Oxidation: $OH^- + h^+ \rightarrow \cdot OH$ (+2.72 V vs SHE)
Reduction: $O_2 + e^- \rightarrow \cdot O_2^-$ (−0.33 V vs SHE)

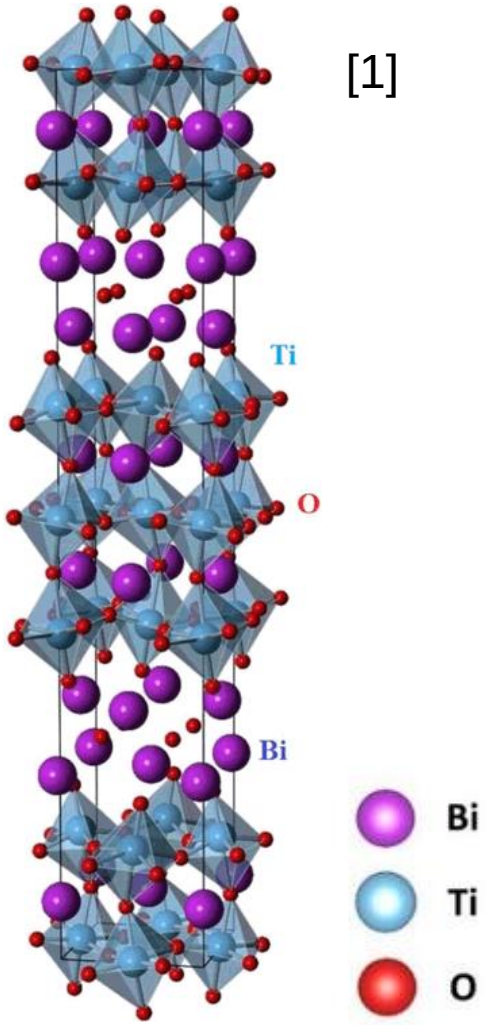
<u>Reactive Oxygen Species (ROS)</u>

- High Oxidizing Power
- Can degrade a wide variety of contaminants
- Short Lifetime, Low Residual Toxicity



Phys. Chem. Chem. Phys., 2023, 25, 25925–25941

Tuning oxygen vacancies (OVs) in $Bi_4Ti_3O_{12}$



[1]

Orthorhombic phase

molten salt process

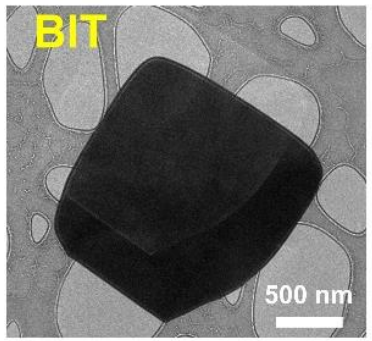
Bi_2O_3

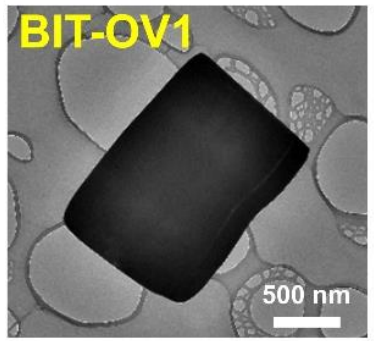
TiO_2

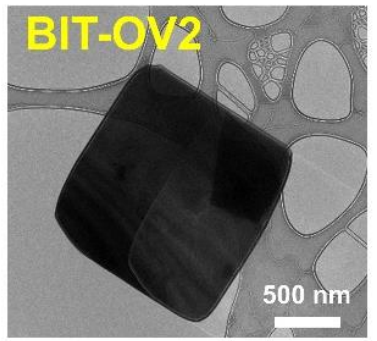
urea

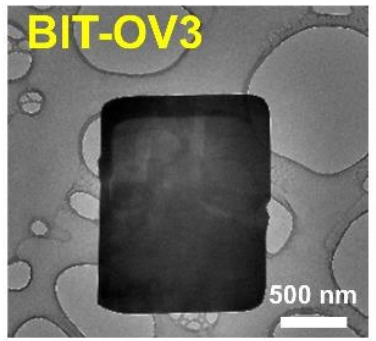
NaCl + KCl

700ºC





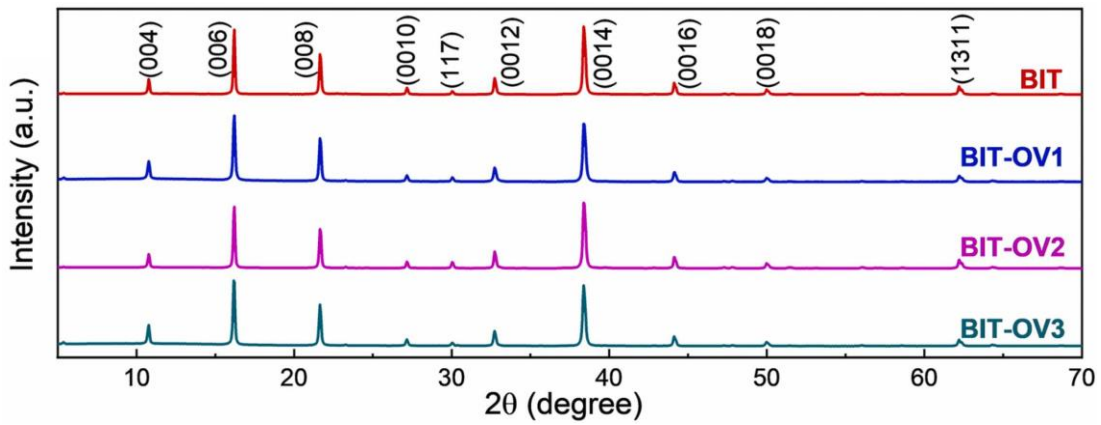




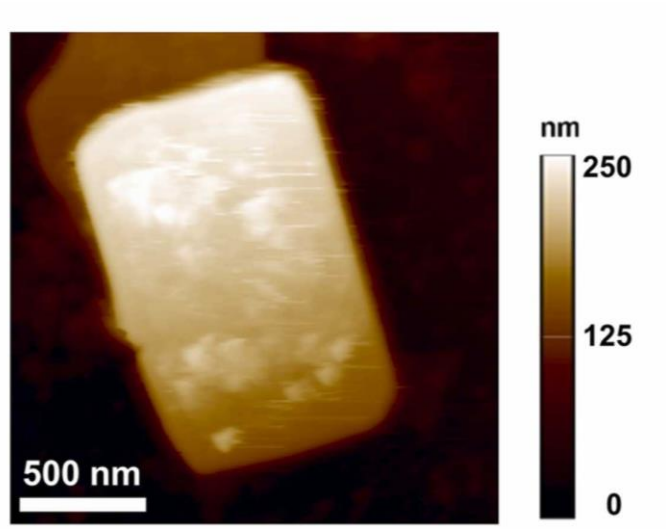
increasing urea concentration

[1] J. Mater. Sci.: Mater. Electron., 28, 7692-7707

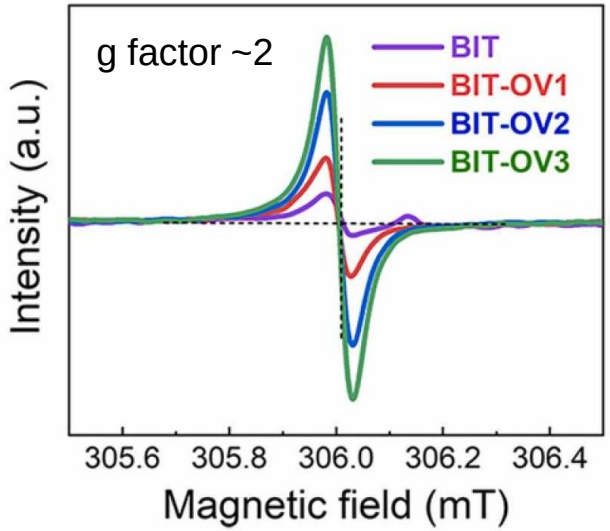
Tuning OVs in $Bi_4Ti_3O_{12}$



Electron Paramagnetic Resonance

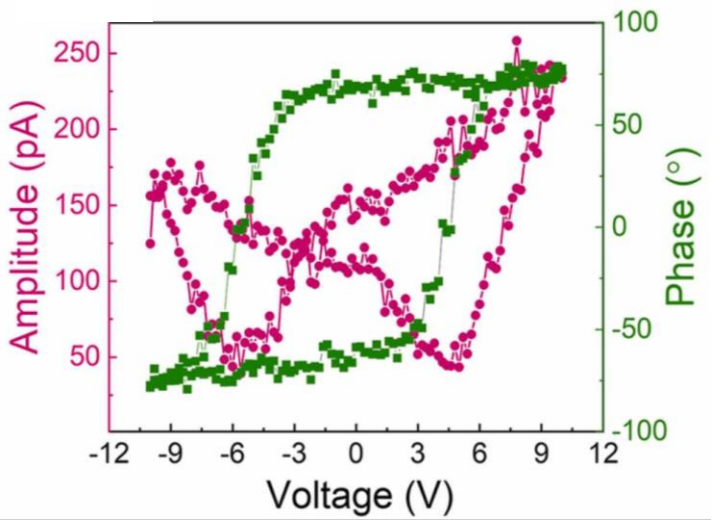


Piezoresponsive Force Microscopy (PFM)

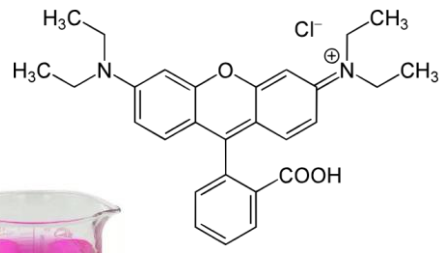


OVs in oxides can trap electrons and form paramagnetic centers (which are detectable by EPR)

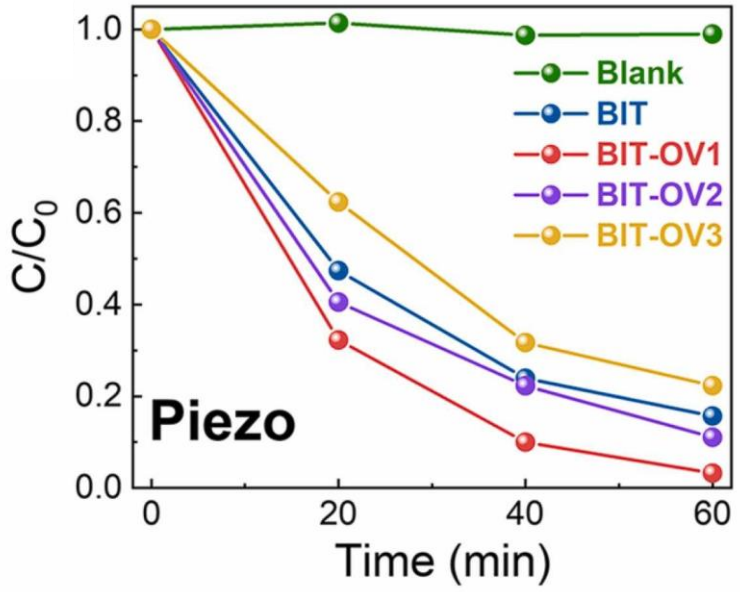
OVs: BIT<BIT-OV1<BIT-OV2<BIT-OV3

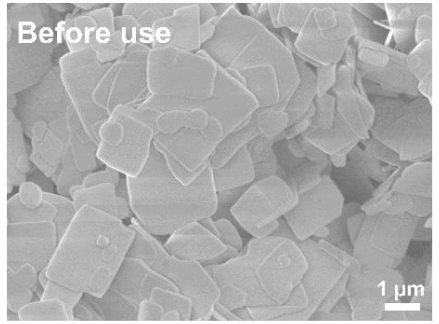


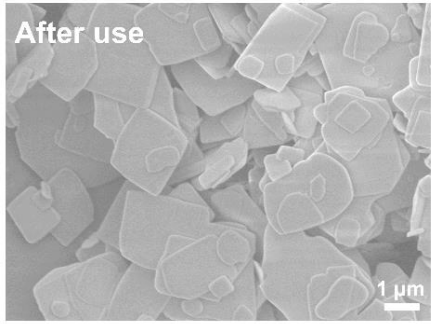
Piezocatalytic performance

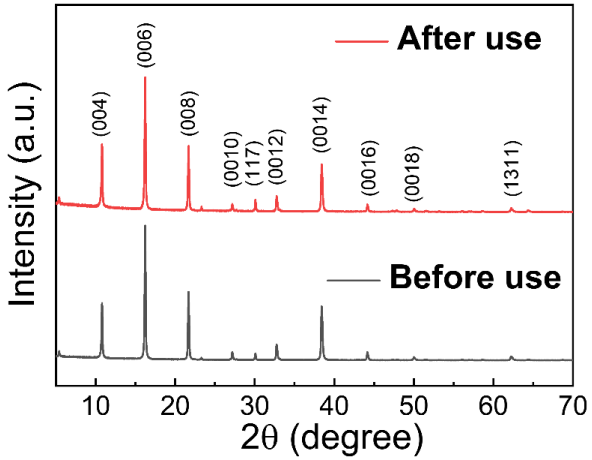


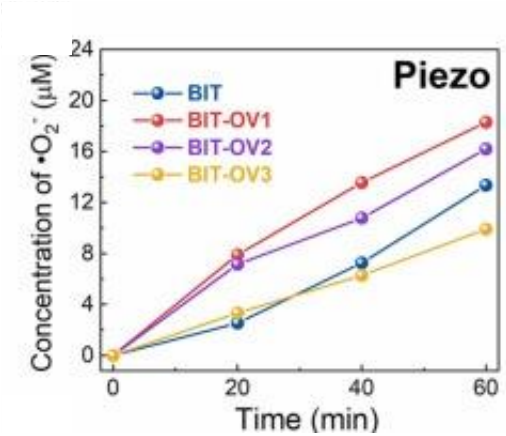
Rhodamine B

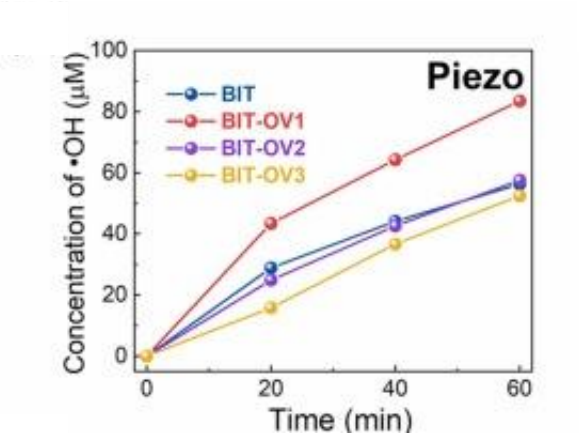


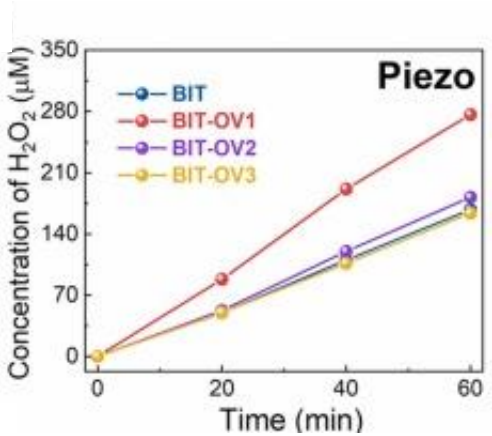






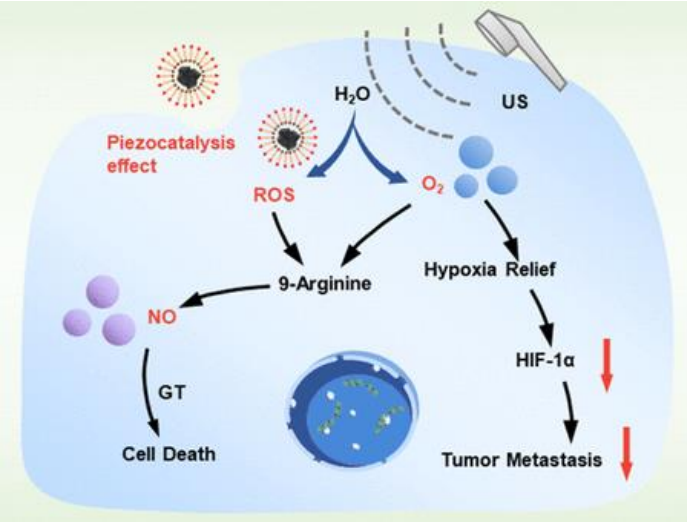






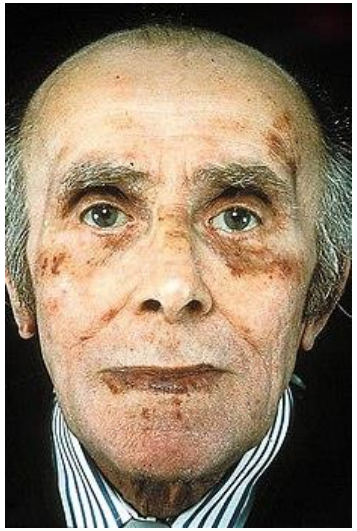
Piezocatalysis in biomedicine

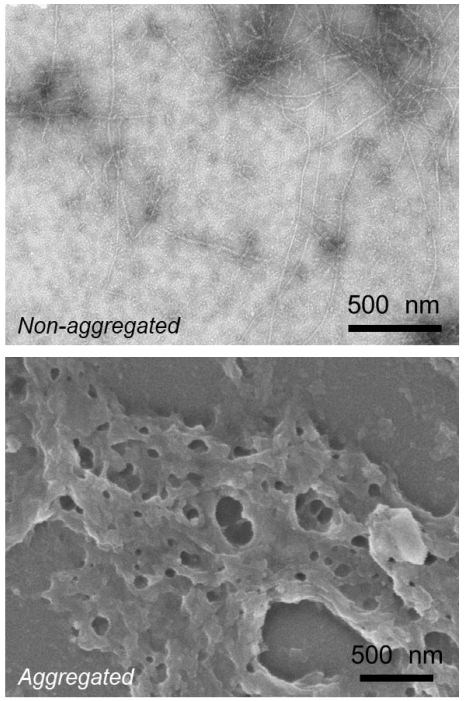
Cancer therapy



ACS Appl. Mater. Interfaces 2023, 15, 12, 15220

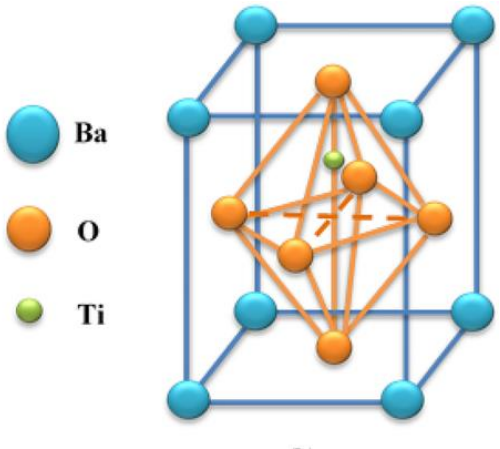
Amyloidosis

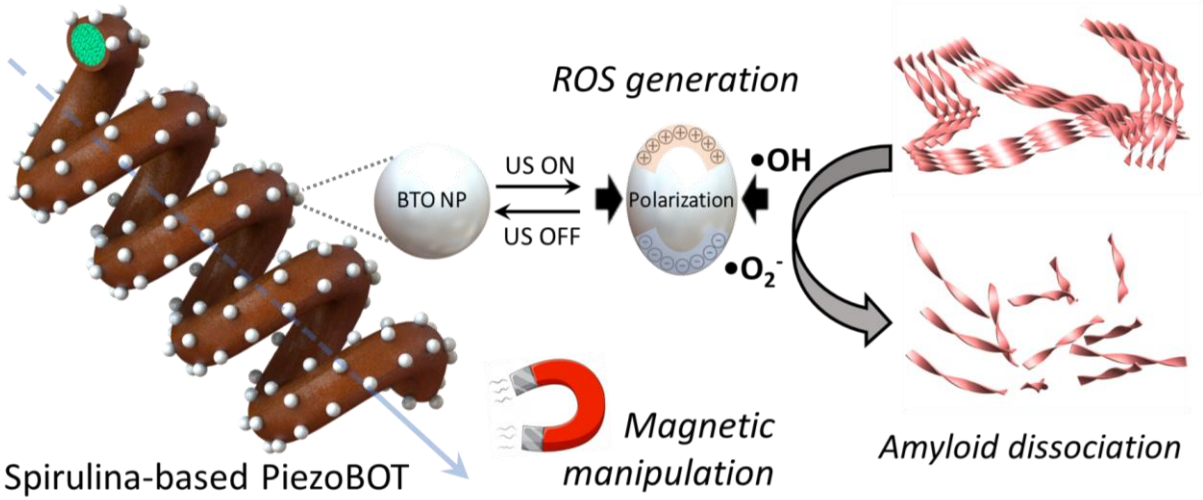




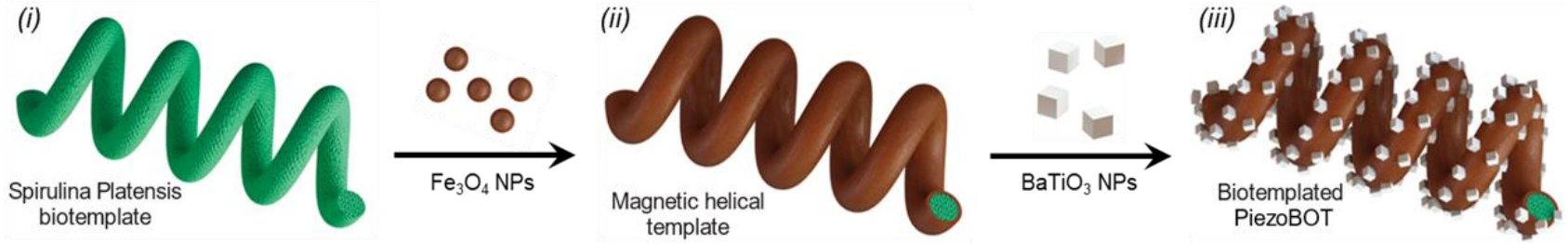
ROS may potentially dissociate amyloid protein aggregates

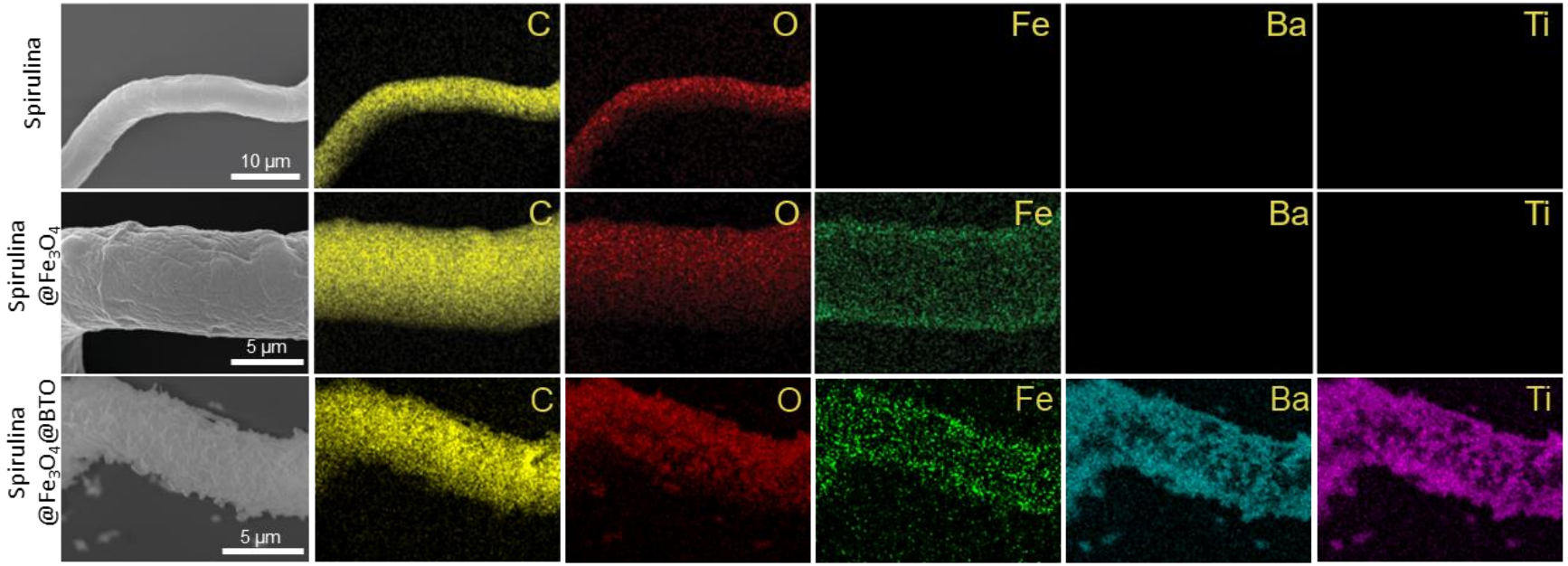
$BaTiO_3$ (BTO)





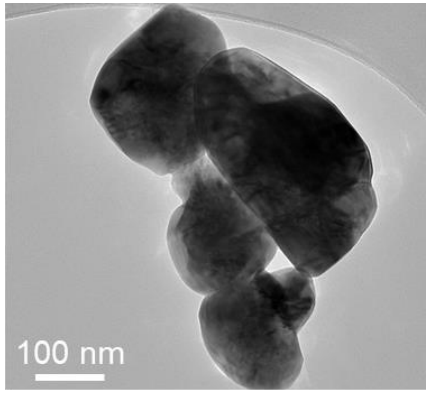
Microrobot fabrication

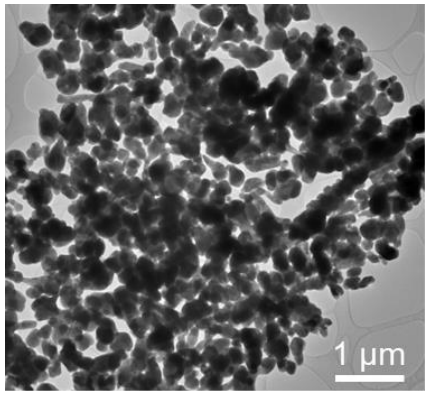


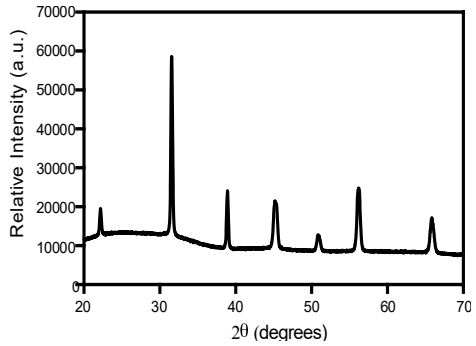


BTO NPs

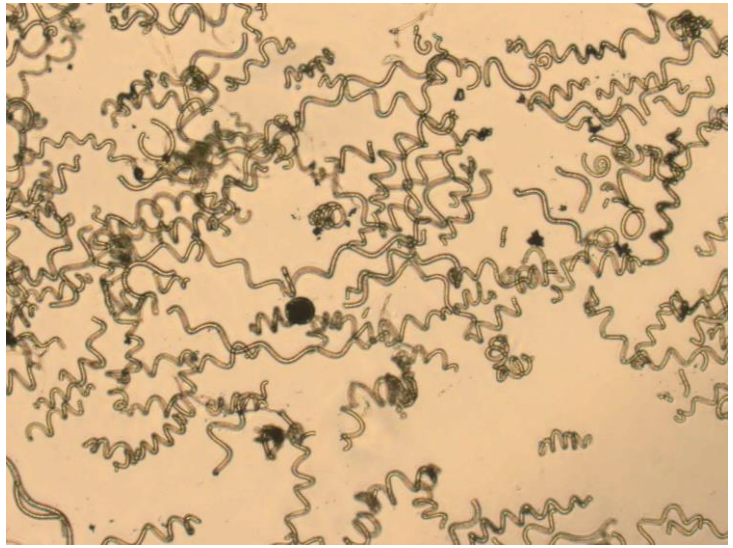
~200-300 nm

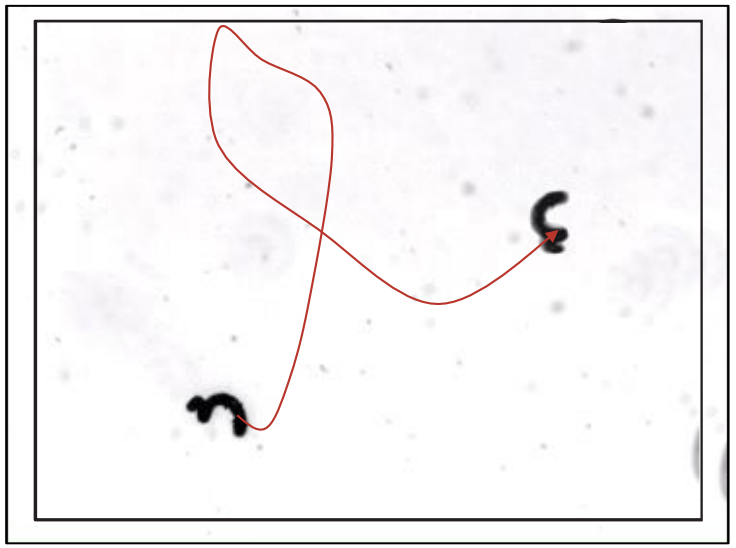


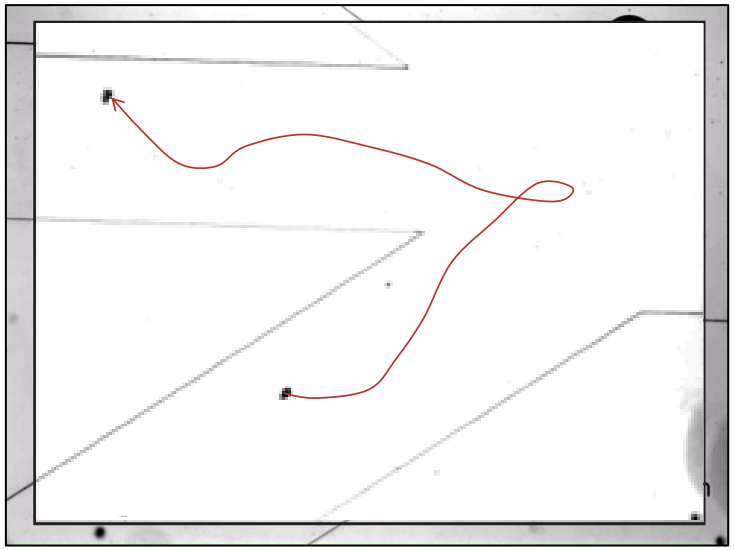




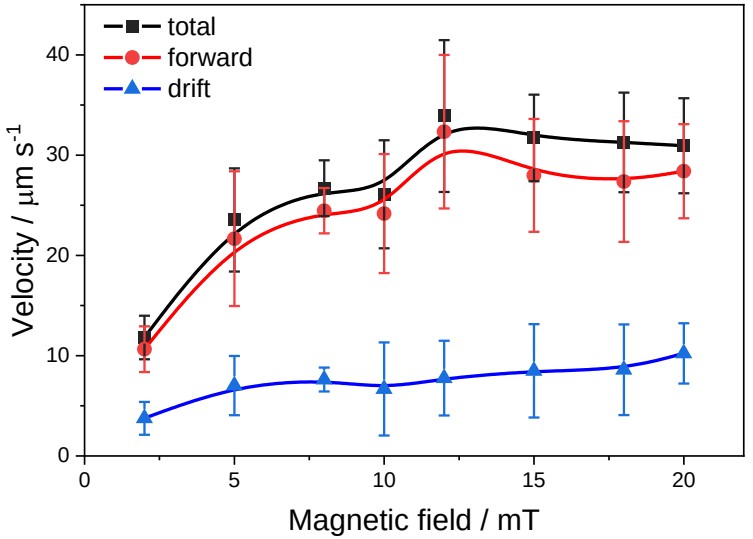
Microrobot manipulation



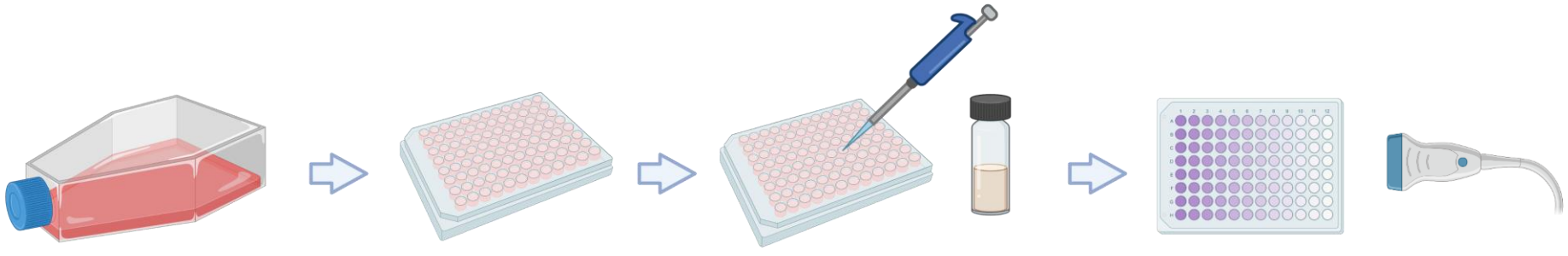


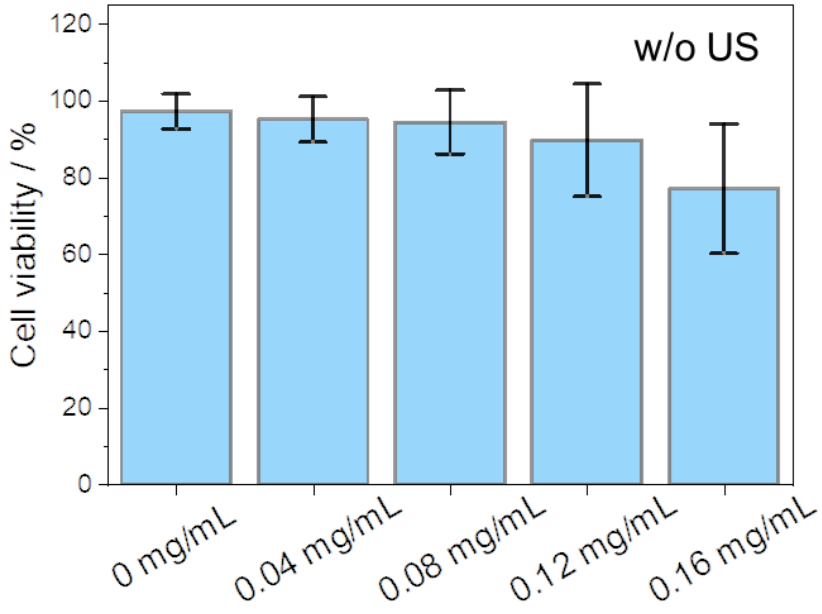


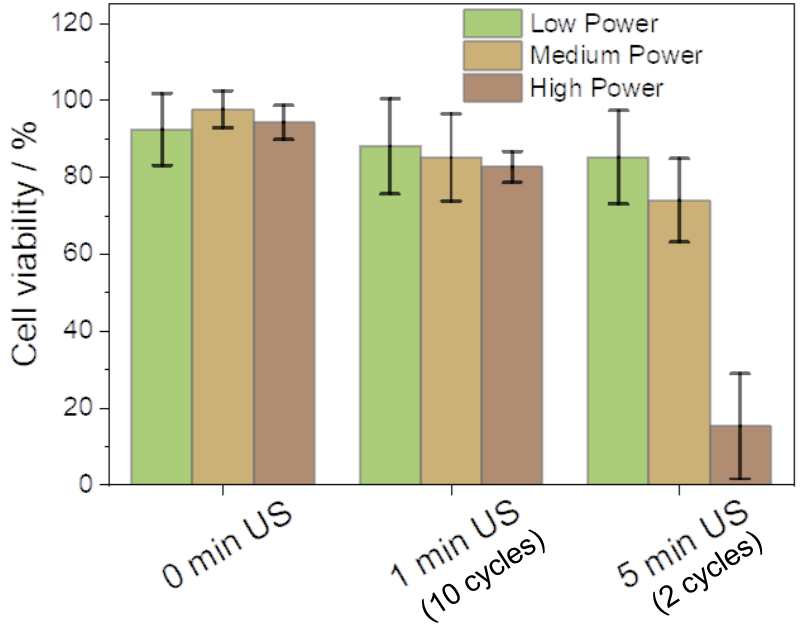
Good magnetic response and easy manipulation



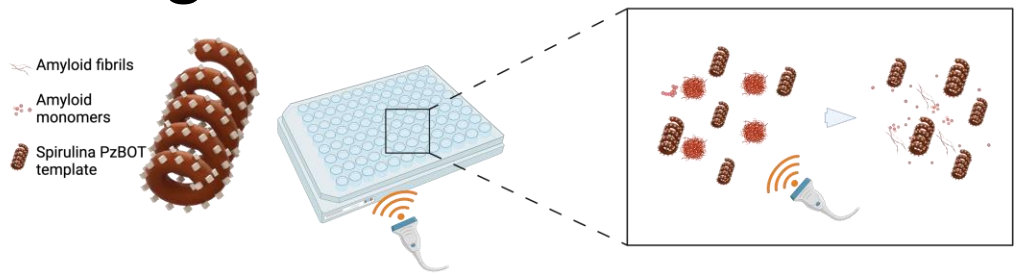
Biocompatibility

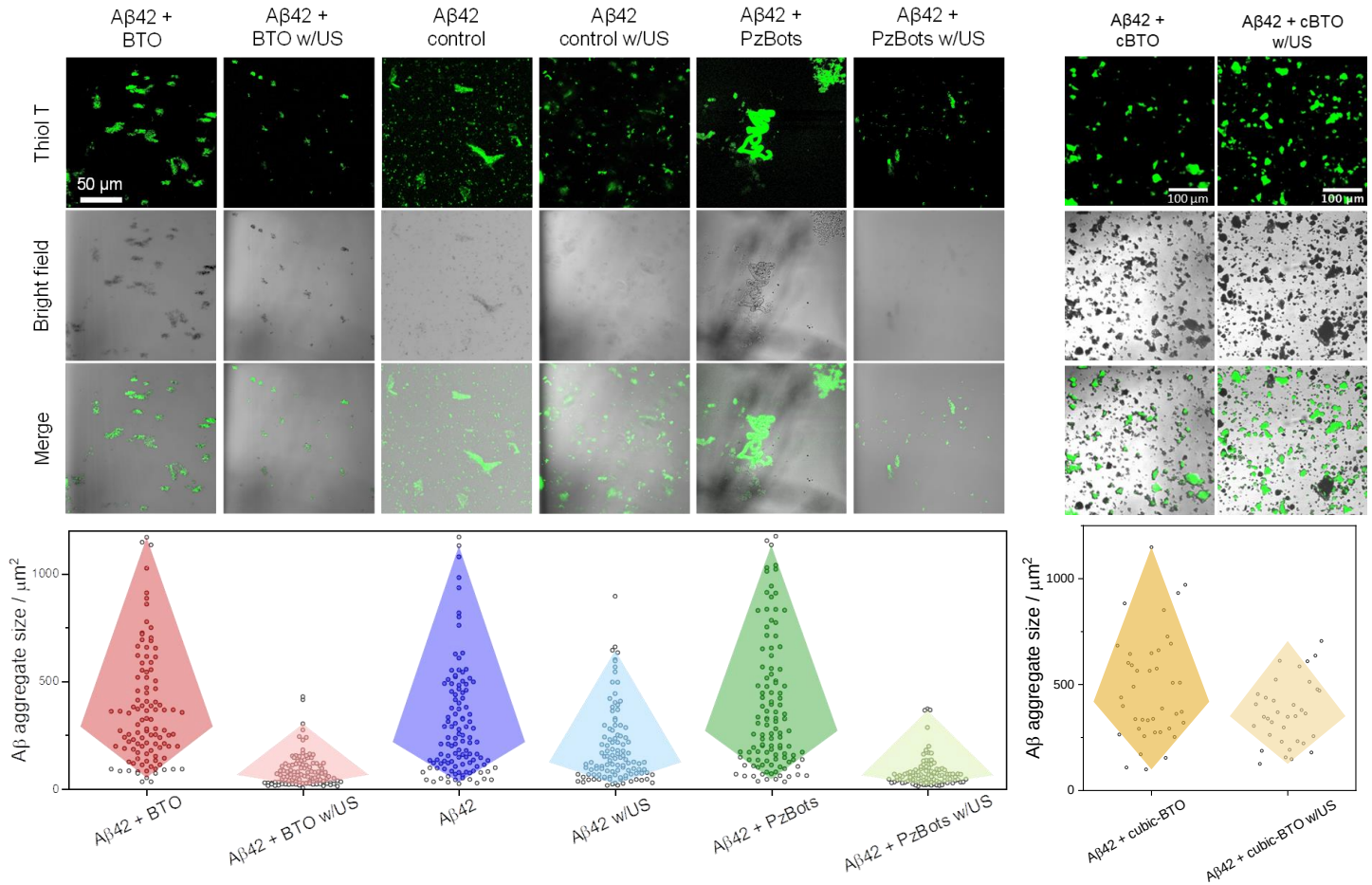


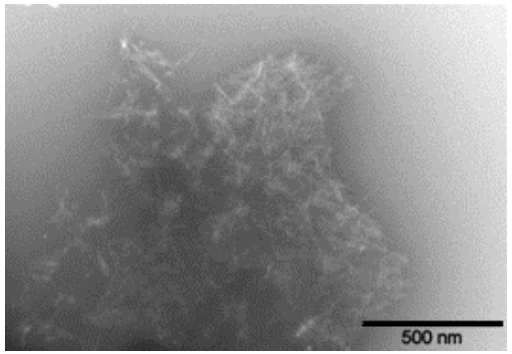




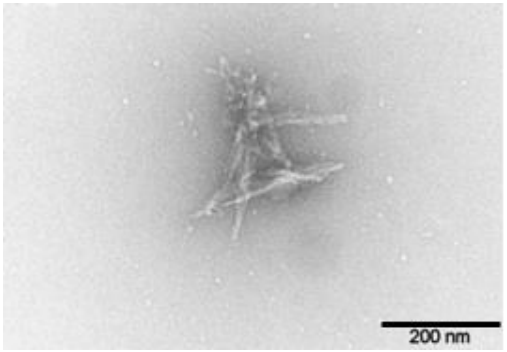
Protein degradation



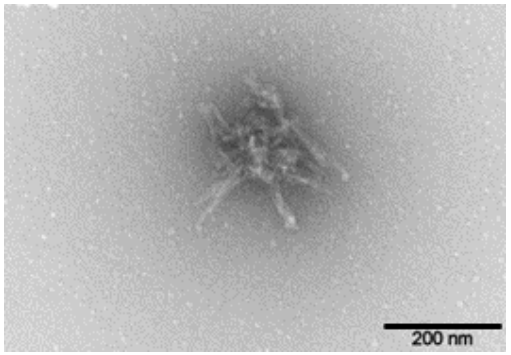




Aβ42 control w/US

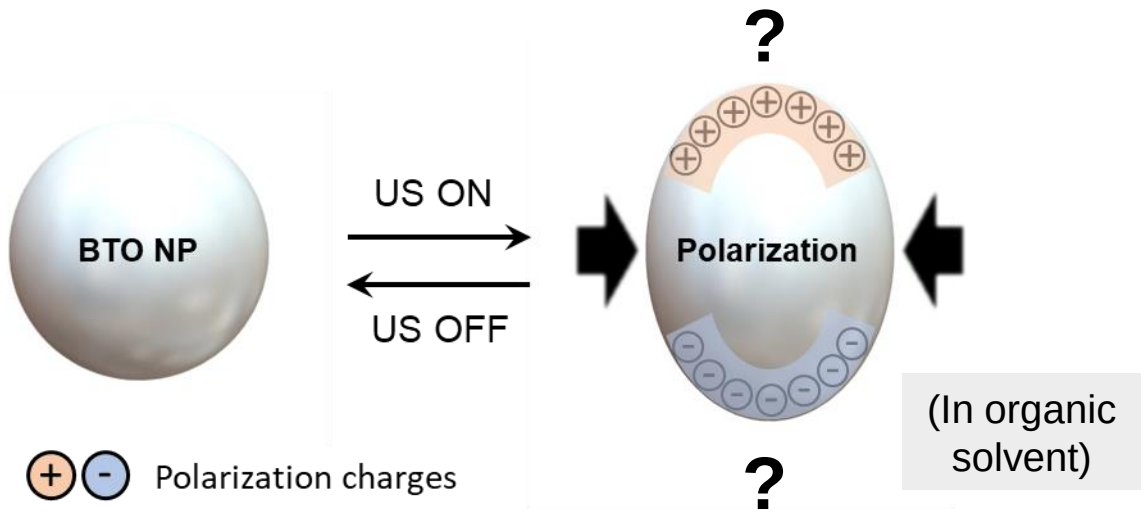


Aβ42 + BTO w/US

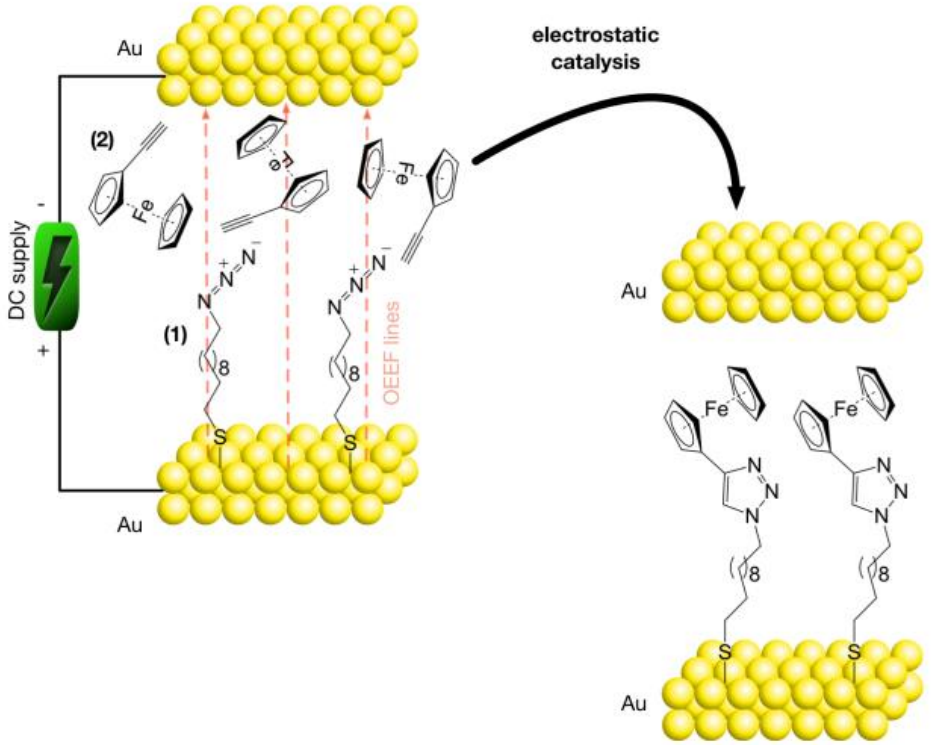


Aβ42 + PzBots w/US

Piezoelectrostatic catalysis

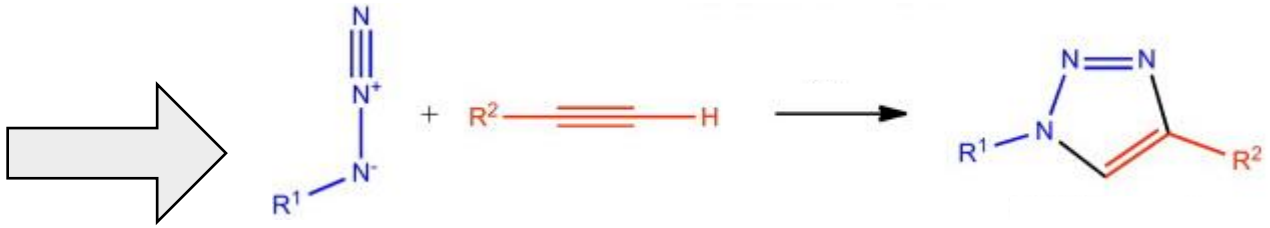


(In organic solvent)



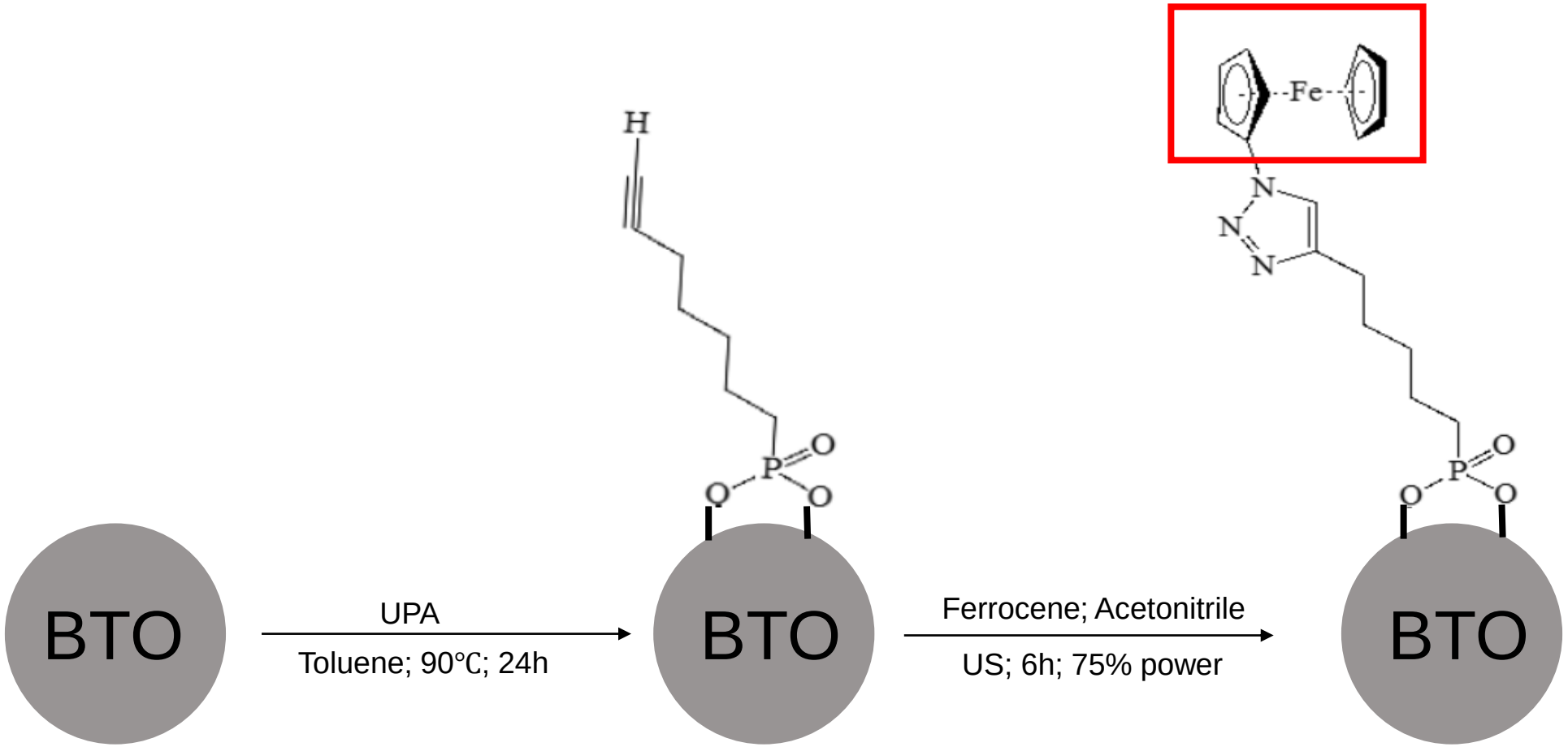
Nature Communication 2024 15 (1), 790

Can the piezoelectric effect catalyze these kinds of reactions?

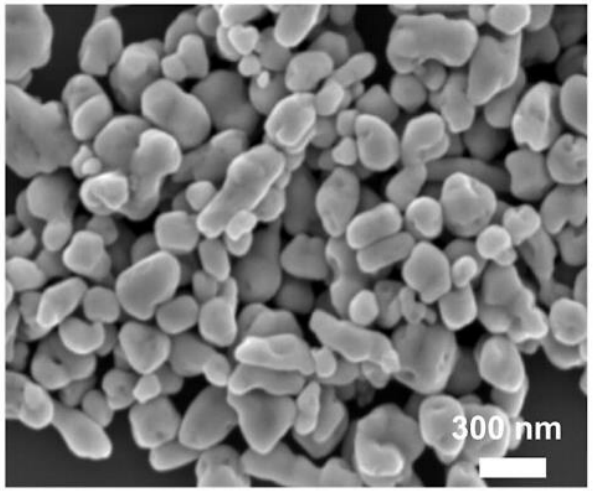


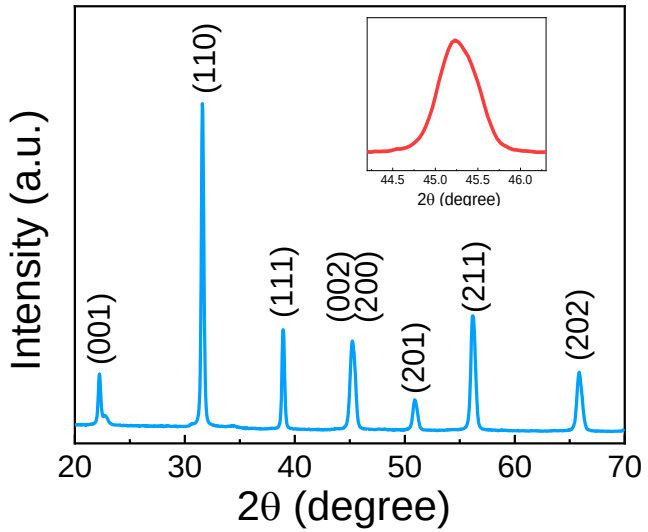
azide–alkyne Huisgen cycloaddition

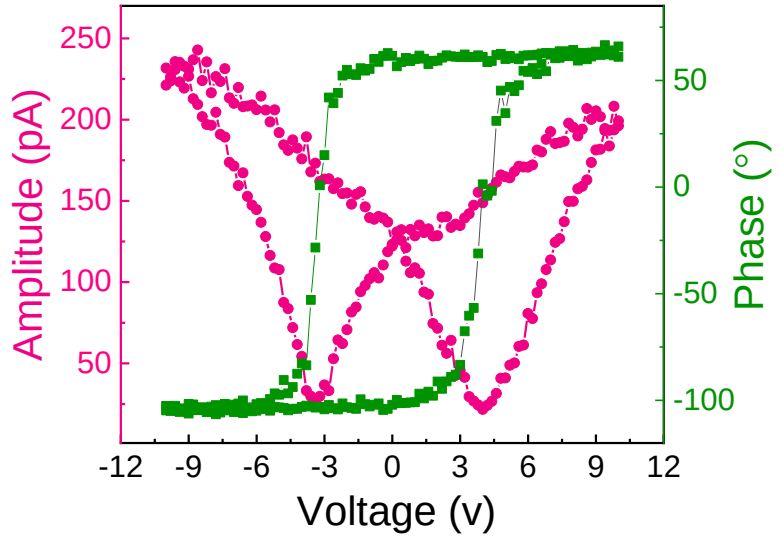
Reaction route

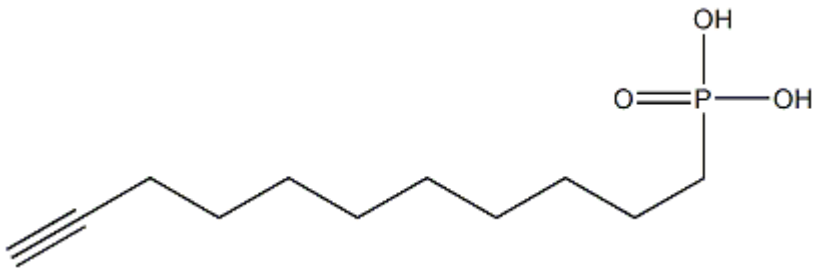


Synthesis and functionalization

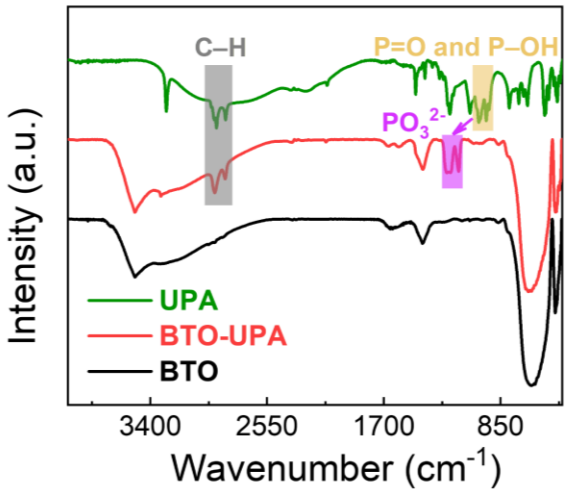


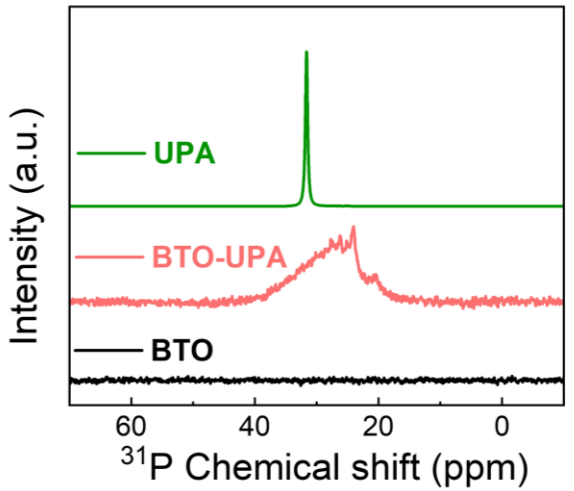




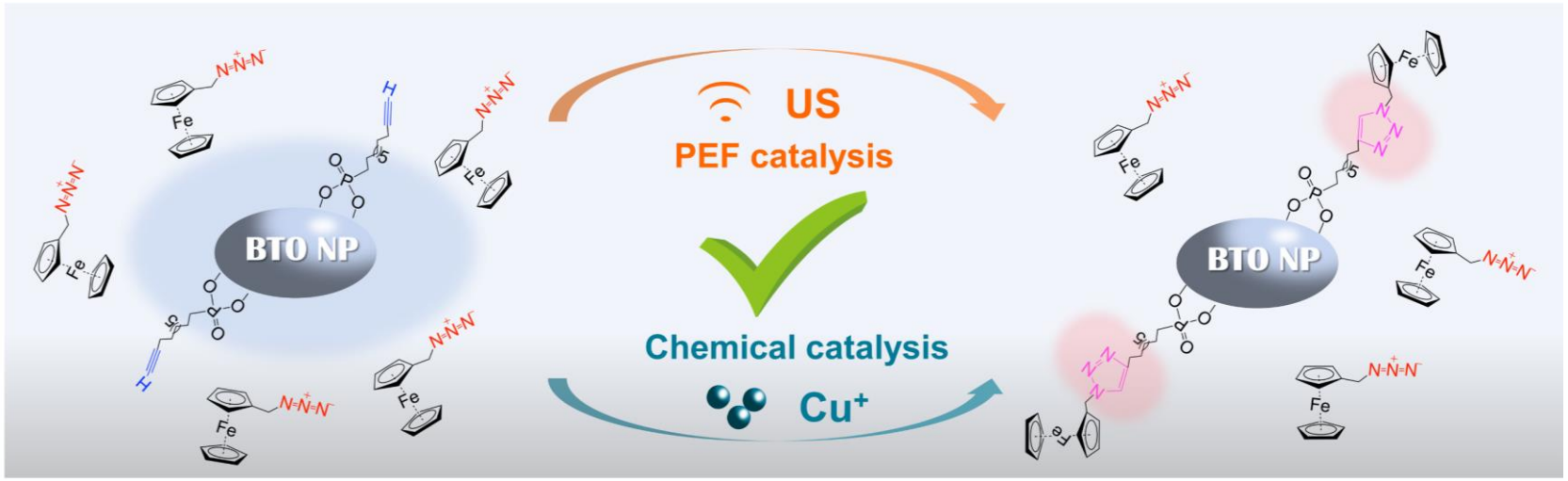


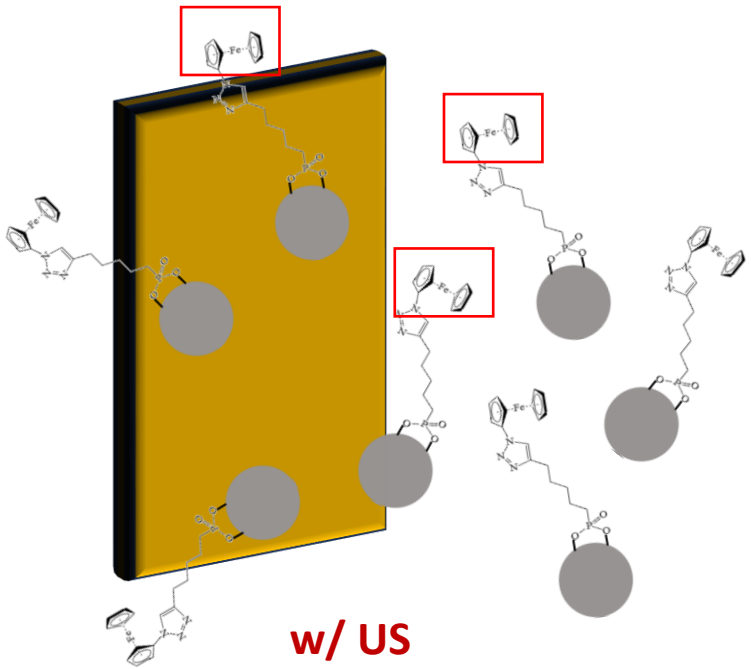
Undecynylphosphonic acid (UPA)

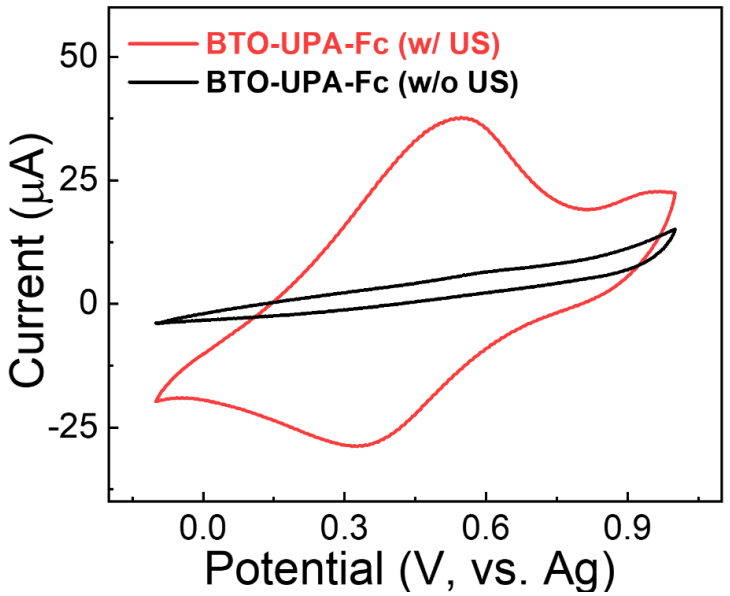


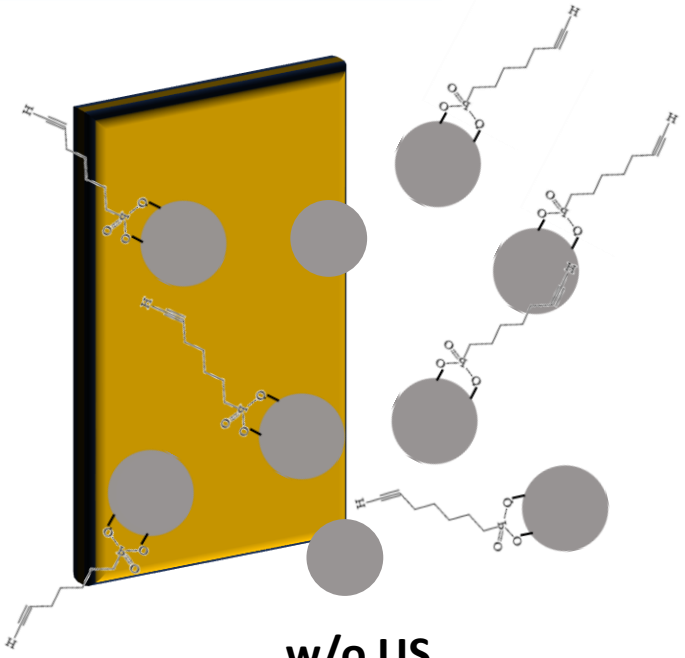


Results after sonication (BTO NPs)

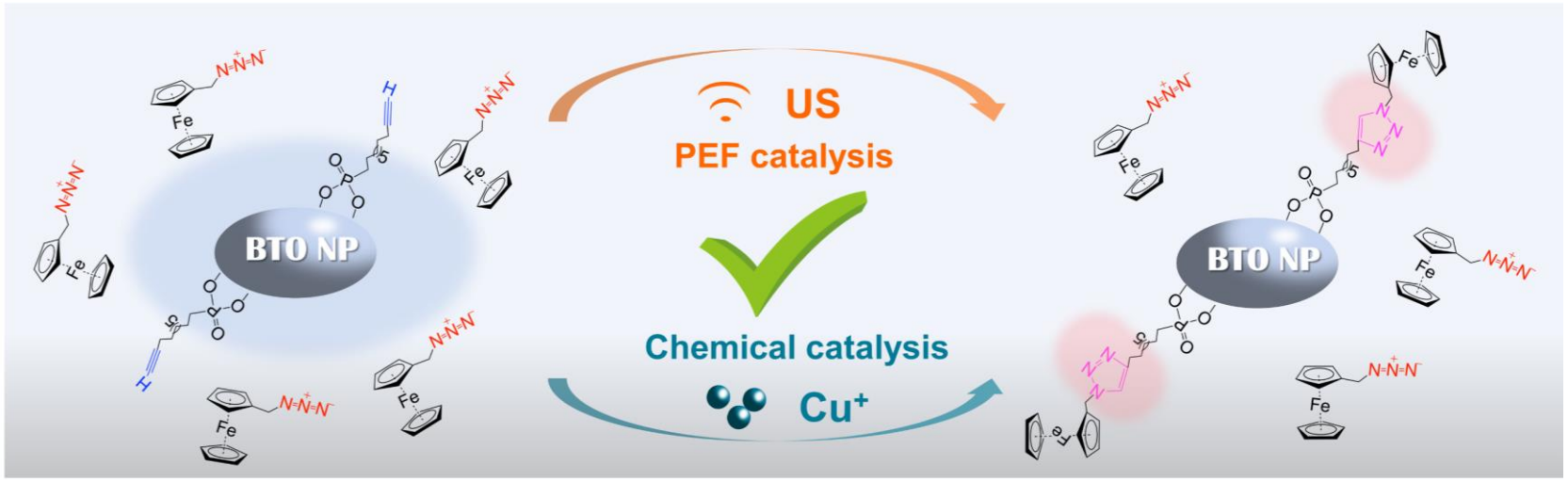


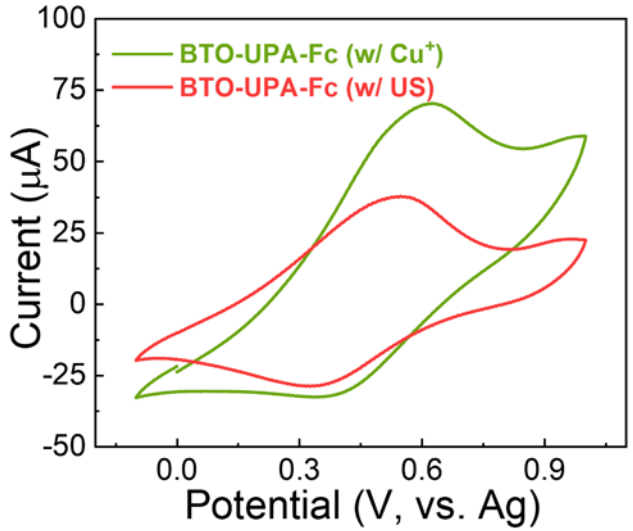


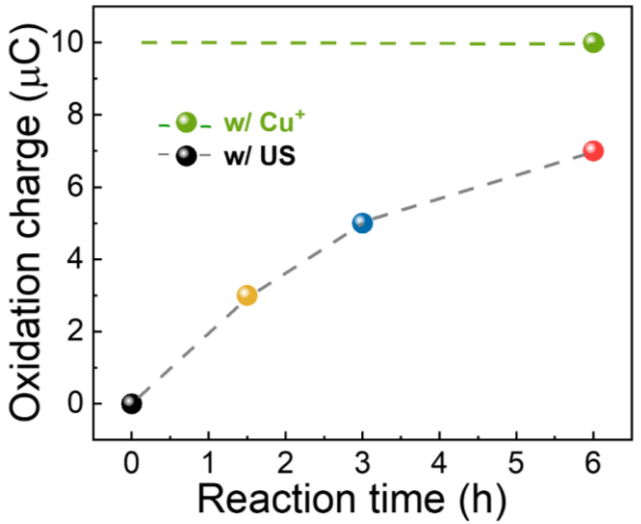




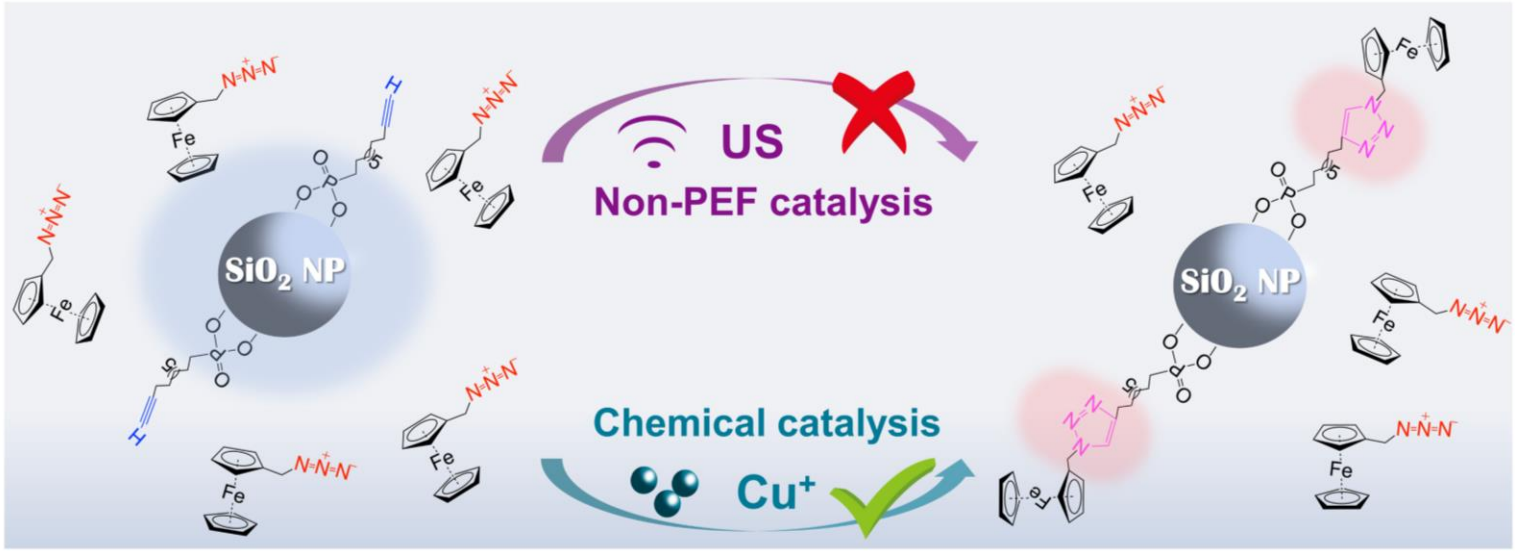
Results after sonication (BTO NPs)

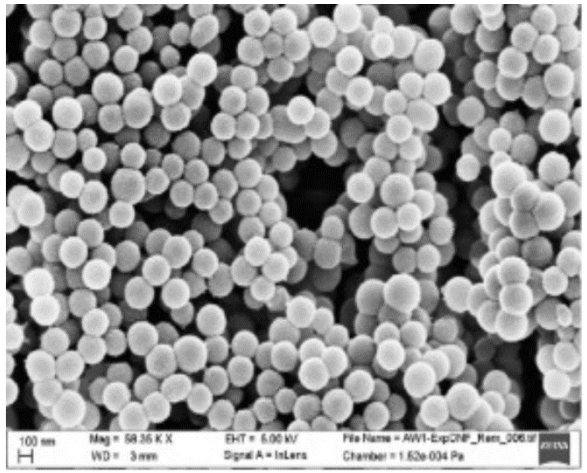


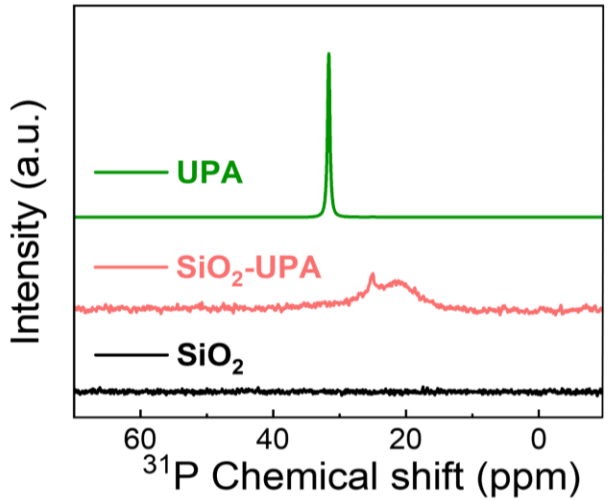


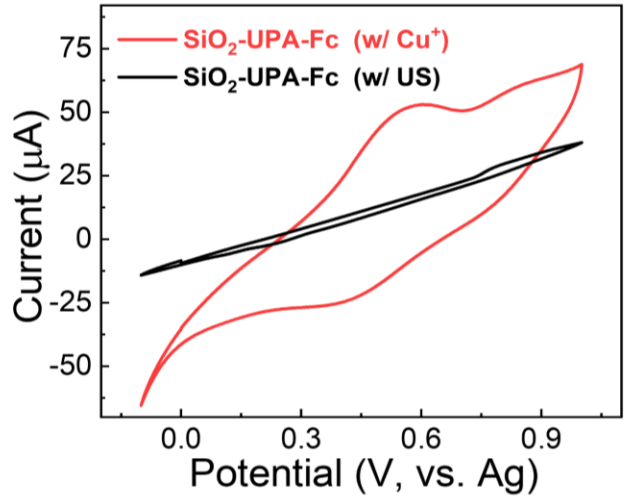


Results after sonication (SiO_2 NPs)

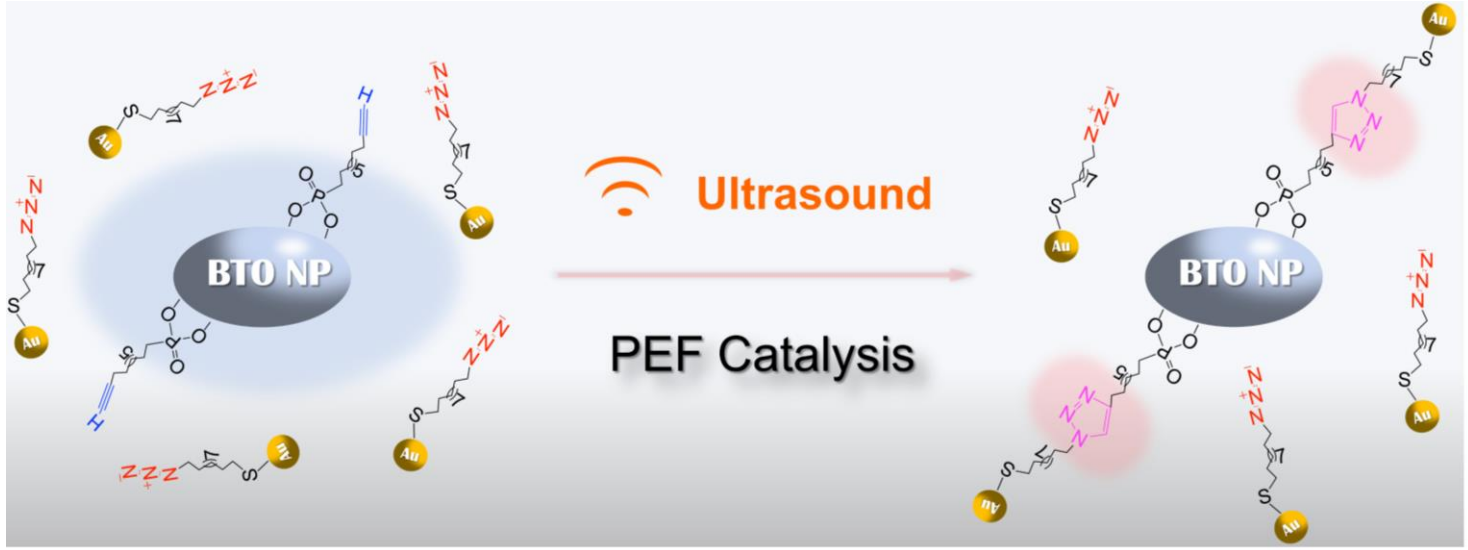


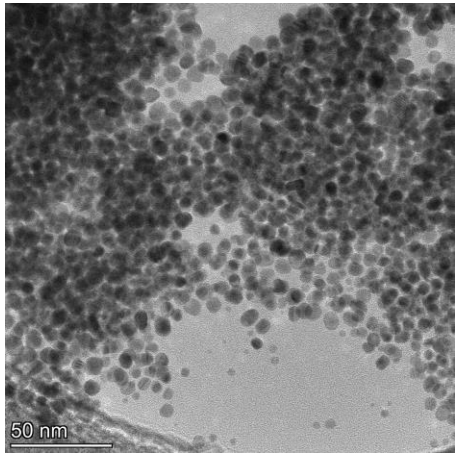


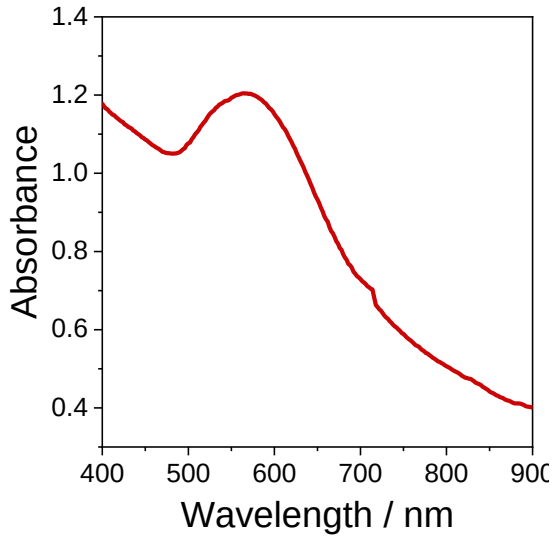


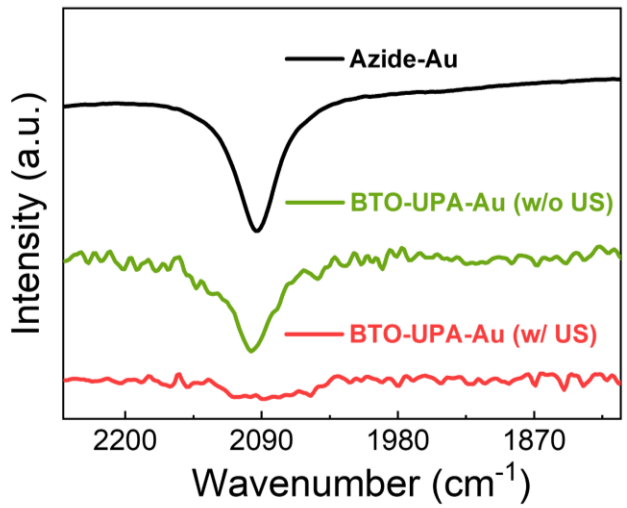


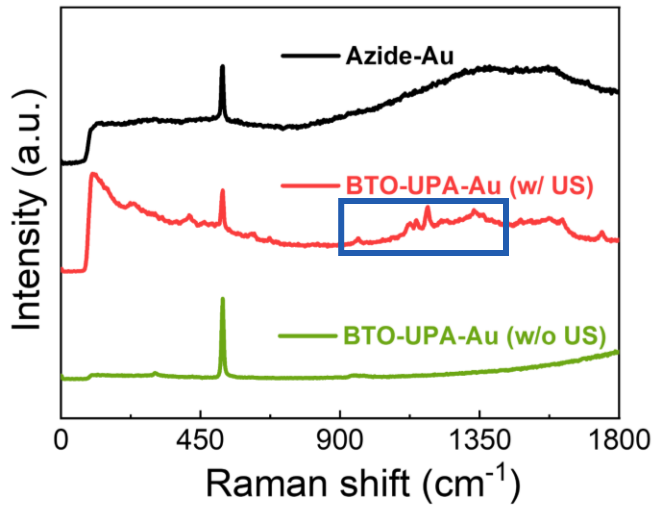
Results after sonication (BTO and Au NPs)











Conclusions

- Piezocatalysis can generate reactive oxygen species (ROS) that efficiently degrade persistent organic pollutants, offering a sustainable solution for wastewater treatment.

- Localized ROS generation via piezocatalysis can enable the dissociation of amyloid proteins, opening new avenues for non-invasive therapies in neurodegenerative diseases.

- The piezoelectrostatic effect can trigger the azide–alkyne Huisgen cycloaddition reaction without metal catalysts, highlighting its potential for synthetic chemistry.

- These approaches illustrate the broad applicability of piezo-driven catalysis across environmental, biomedical, and synthetic applications.

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