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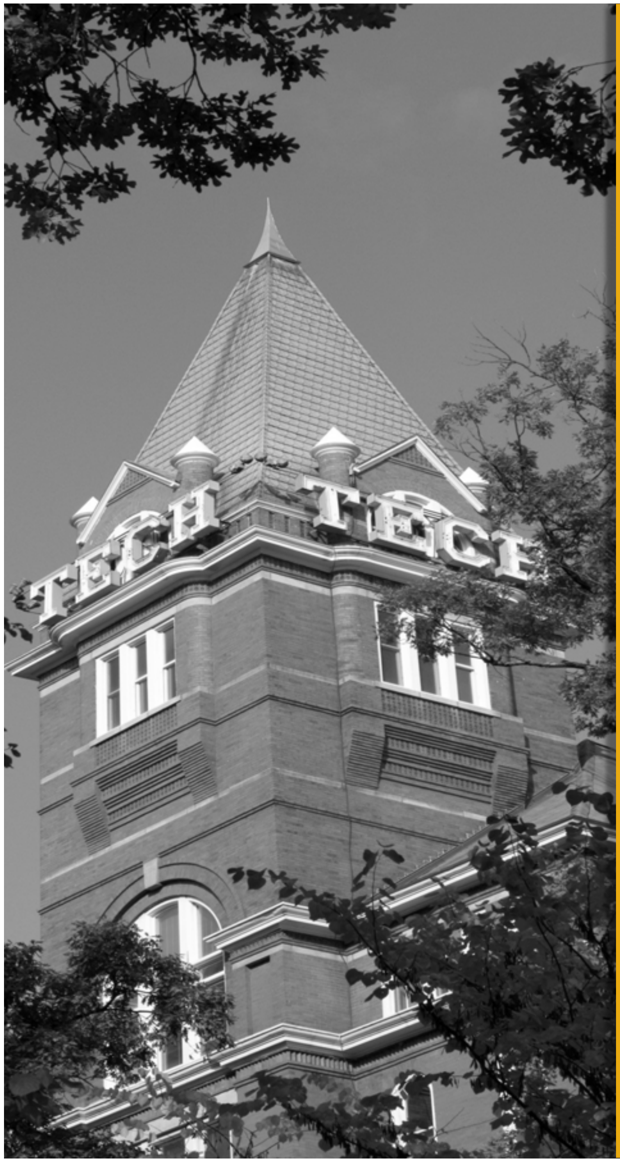

Locally Enhanced Electric Field Treatment (LEEFT) for Disinfection

Xing Xie

October 5, 2022

Georgia Tech School of Civil and Environmental Engineering
College of Engineering

Acknowledgements

- PhD/MS Students
  - **Ting Wang**
  - Cecilia Yu
  - Mourin Jarin
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  - Wensi Chen, PhD
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  - Betty Sui, MS
  - Nissim Gore-Datar, MS
  - Shui Jing, MS
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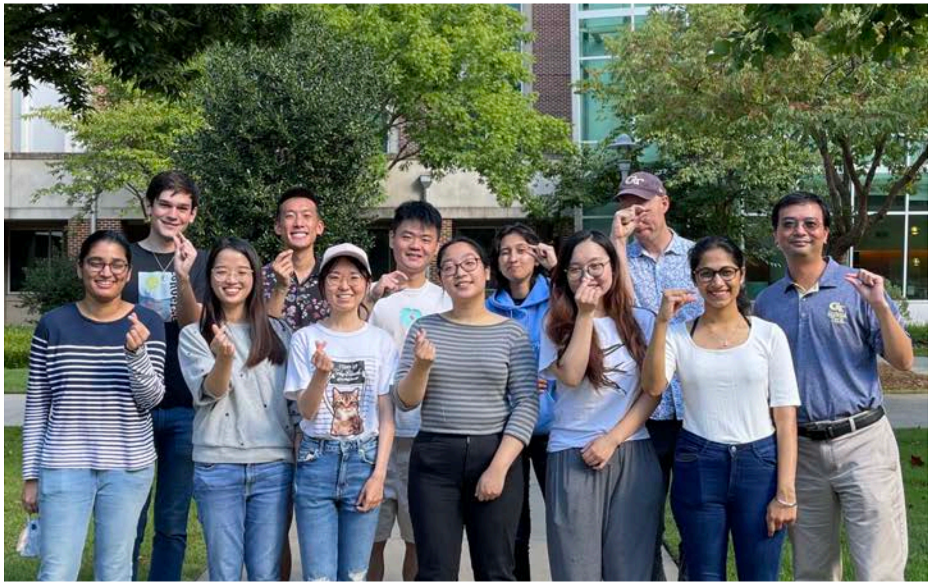
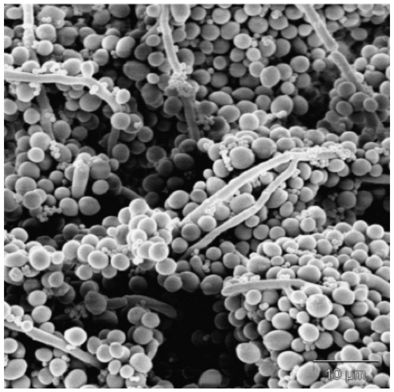
- Collaborators
- Lab/Administration Support

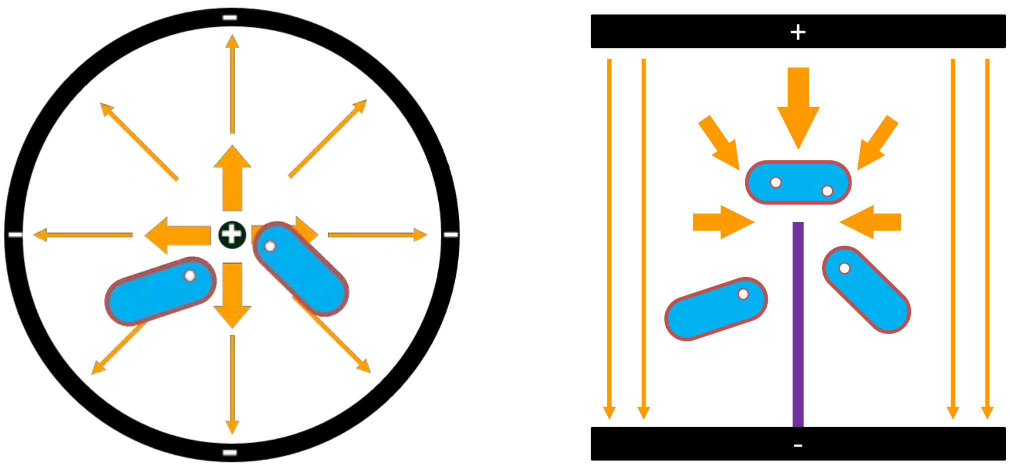


Bacteria Inactivation

- Seeking for efficient bacteria inactivation methods is important.

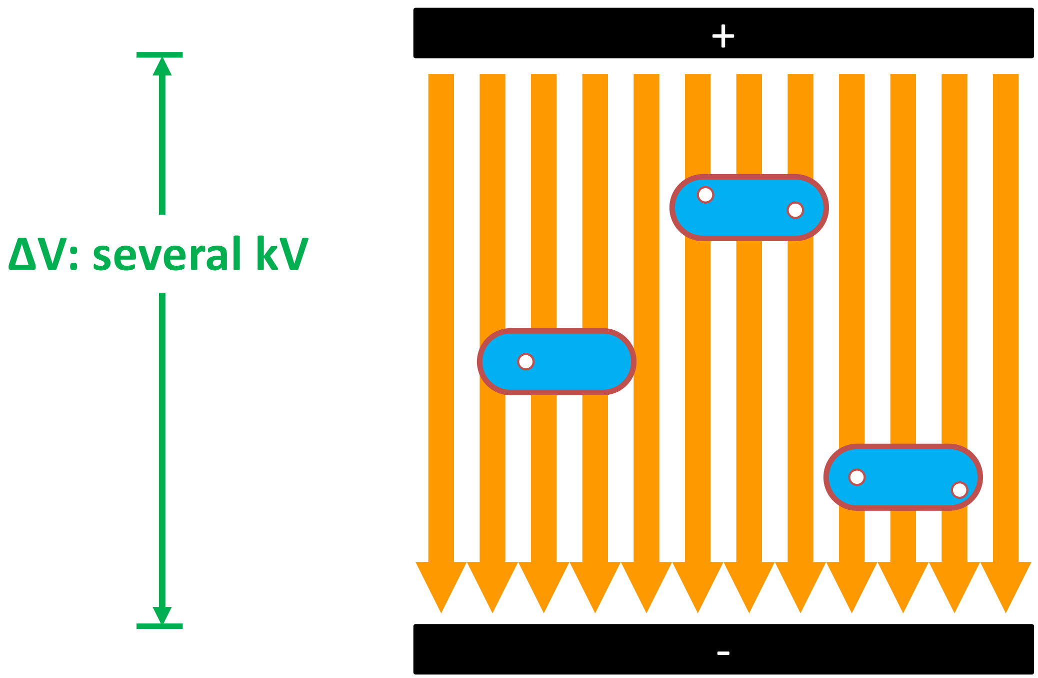
Public health	Food safety	Industry
Water disinfection	Food sterilization	Biofouling control
		
Chlorination	Heat treatment	Biocidal coating
Disinfection-by-products	Nutrition and flavor loss	Environmental hazards

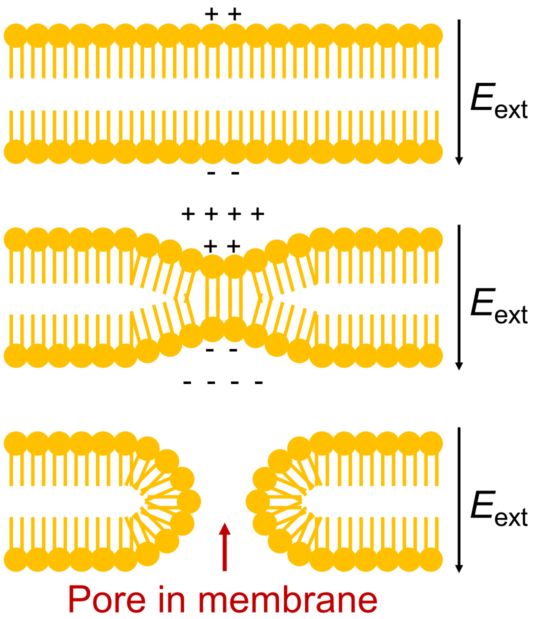
Locally Enhanced Electric Field Treatment (LEEFT)



Environmental Science Technology, 2016, 50: 7641-7649
Environmental Science: Water Research & Technology, 2018, 4, 872-881
Scientific Reports, 2018, 8, 15832
Journal of Materials Chemistry A, 2018, 6, 18813-18820
Advanced Energy Materials, 2019, 1901320
Chemical Engineering Journal, 2019, 369, 1005-1013
Journal of Materials Chemistry A, 2019, 7, 7347-7354
Environment international, 2019, 128: 30-36
Environment International, 2019, 132: 105040
Environmental Science: Nano, 2020, 7: 397-403
Environmental Science: Nano, 2020, 7: 2021-2031
Environmental Science Technology, 2020, 54: 14017–14025
Frontier of Environmental Science & Engineering, 2020, 14: 78
Journal of Materials Chemistry A, 2020, 8, 12262-12277
npj Clean Water, 2020, 3(1): 1-9
Journal of Hazardous Materials, 2020, 400(5): 123320
Water Research, 2021, 207: 117817
Nano Letters, 2022, 2: 860-867

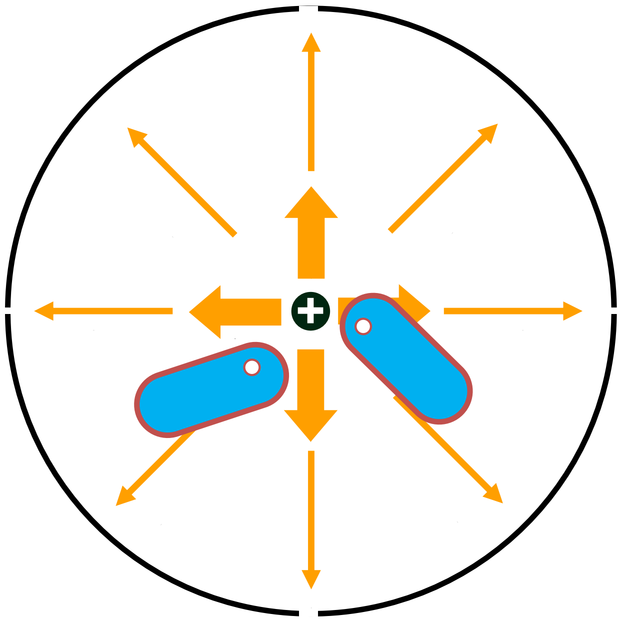
Electric Field Treatment (EFT)



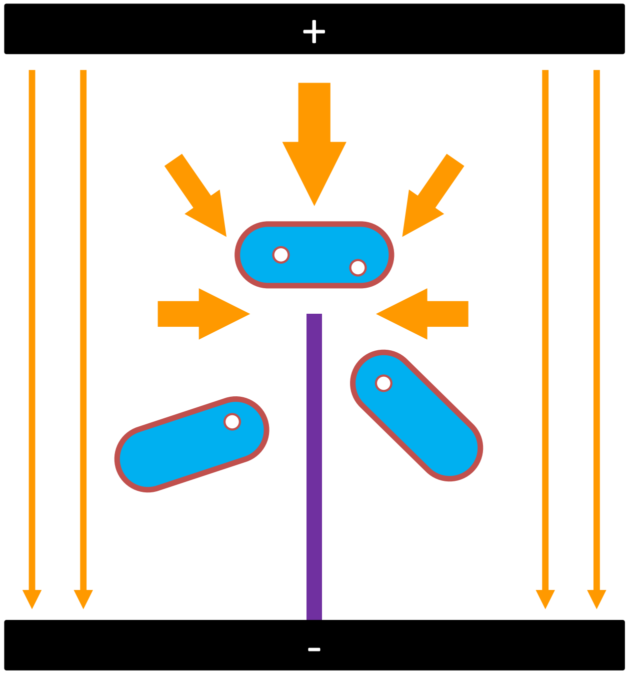


Locally Enhanced Electric Field Treatment (LEEFT)

Macro-scale enhancement



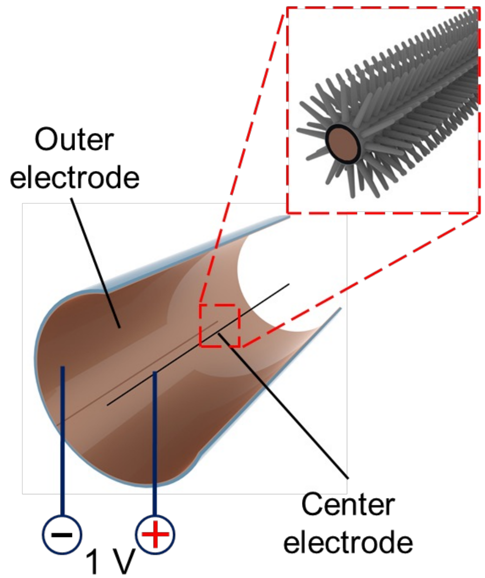
Micro-scale enhancement



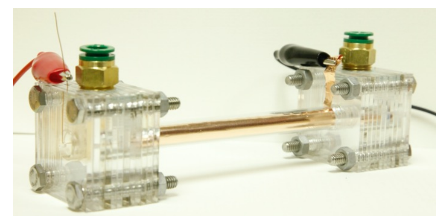
J. Zhou, et al. *Front. Environ. Sci. Eng.* 2020, 14(5): 78, J. Zhou, et al. Environ. Sci. Nano. 2020, 7 (2), 397-403

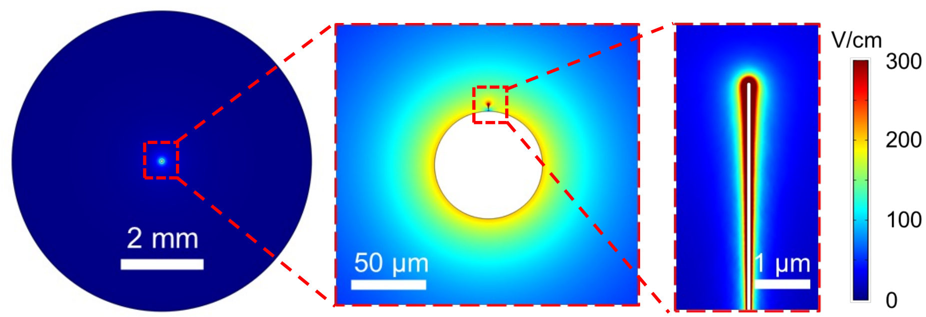
Tubular Coaxial-electrode LEEFT

- Combine Macro- & Micro-scale enhancement
- **Tubular coaxial-electrode** configuration
  - **Two levels** of electric field enhancement



Length: ~12 cm
Diameter: ~1 cm





Electric field simulation

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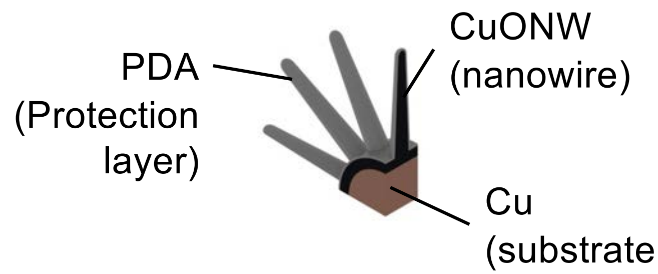
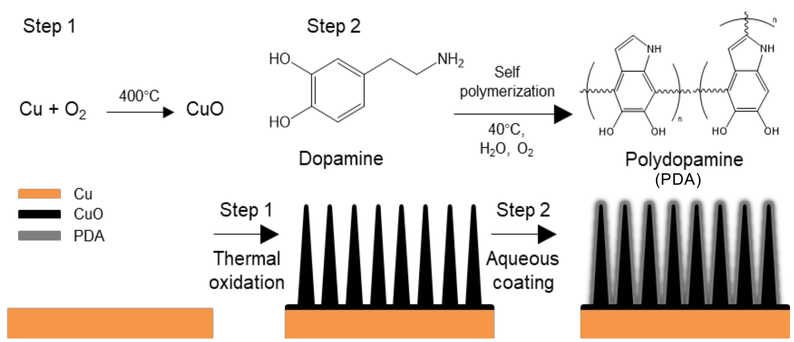
Tubular Coaxial-electrode LEEFT

- Electrode fabrication
  - PDA-CuONW-Cu

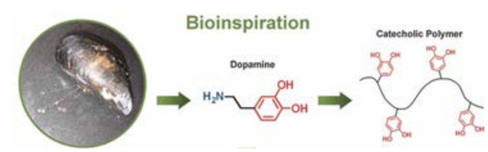
Copper wires



Electrode structure



Fabrication processes



Polydopamine (PDA)

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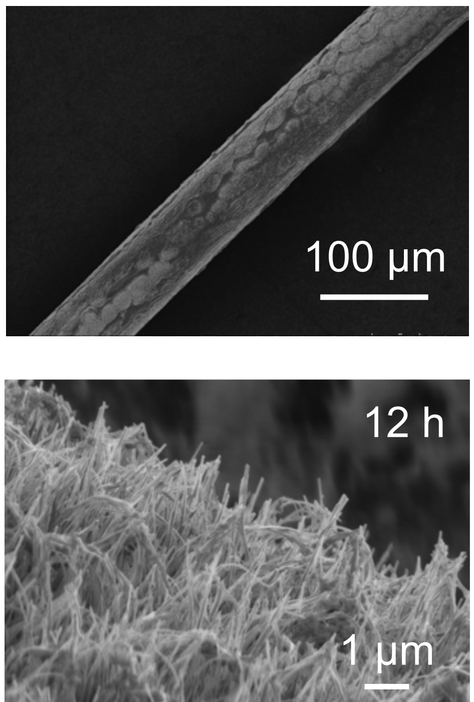
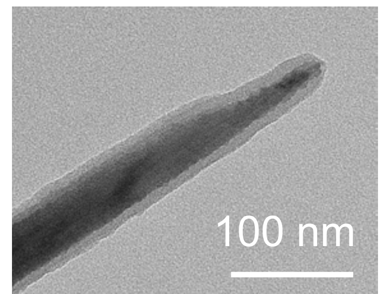
Tubular Coaxial-electrode LEEFT

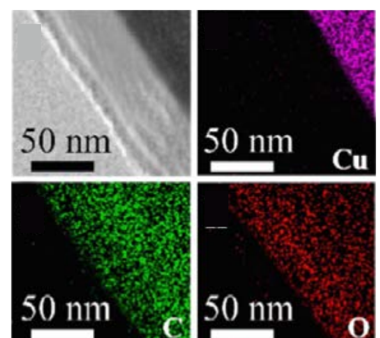
- Electrode morphology



SEM



TEM



EDX

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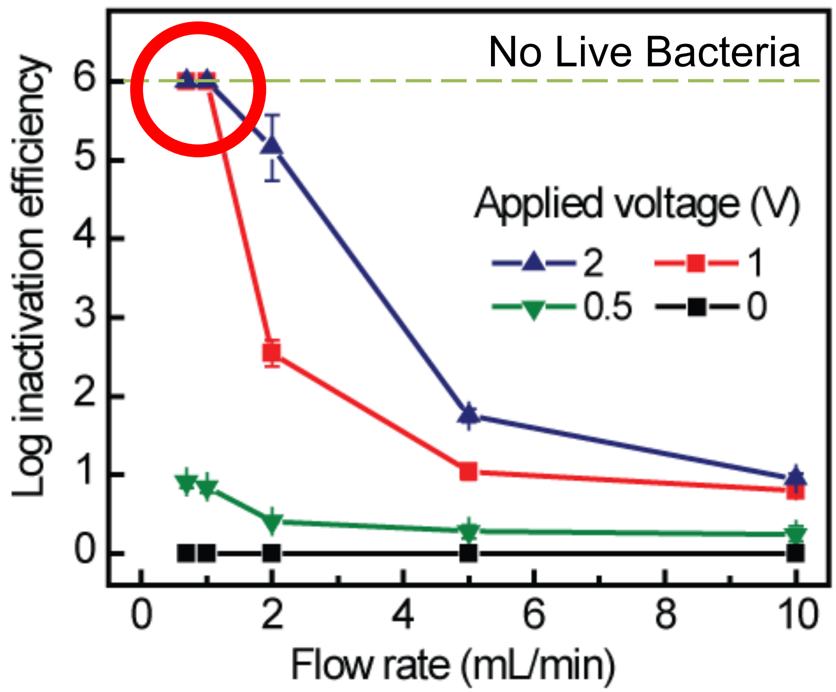
Tubular Coaxial-electrode LEEFT

- Water disinfection performance (*E. coli*)
  - **99.9999%** inactivation with **1 V**



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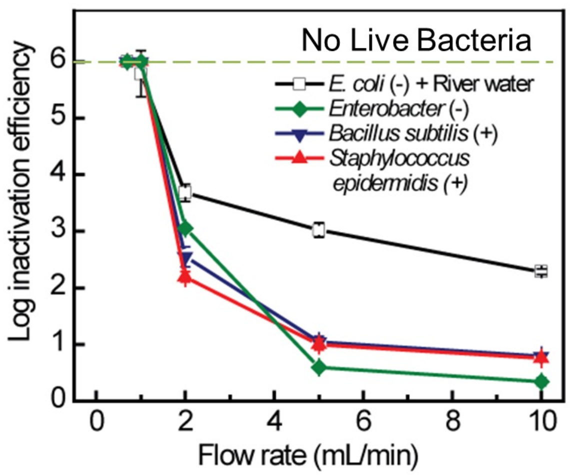
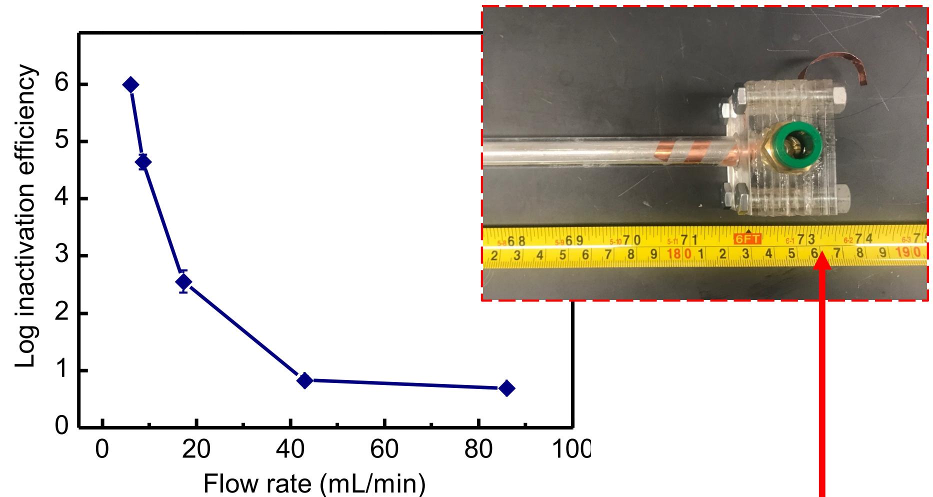
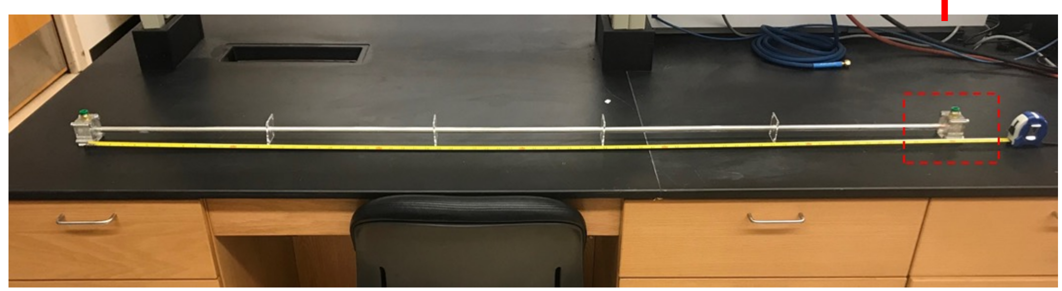
Tubular Coaxial-electrode LEEFT

- Effective against *multiple strains of bacteria*





- Highly *scalable* (180 cm)



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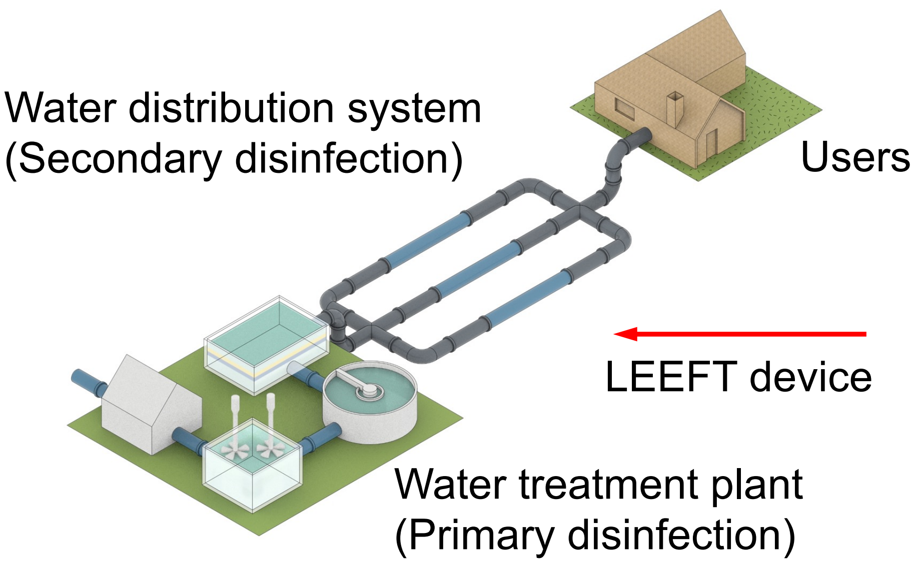
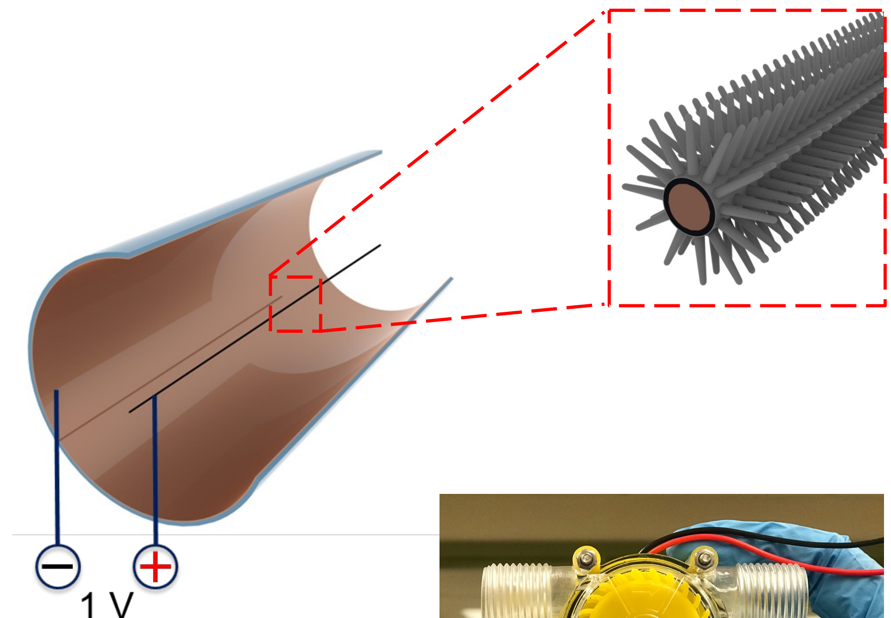
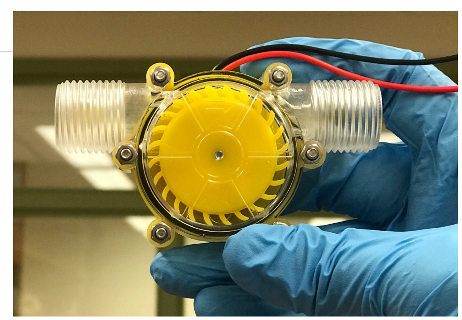
- Potential application in pipelines

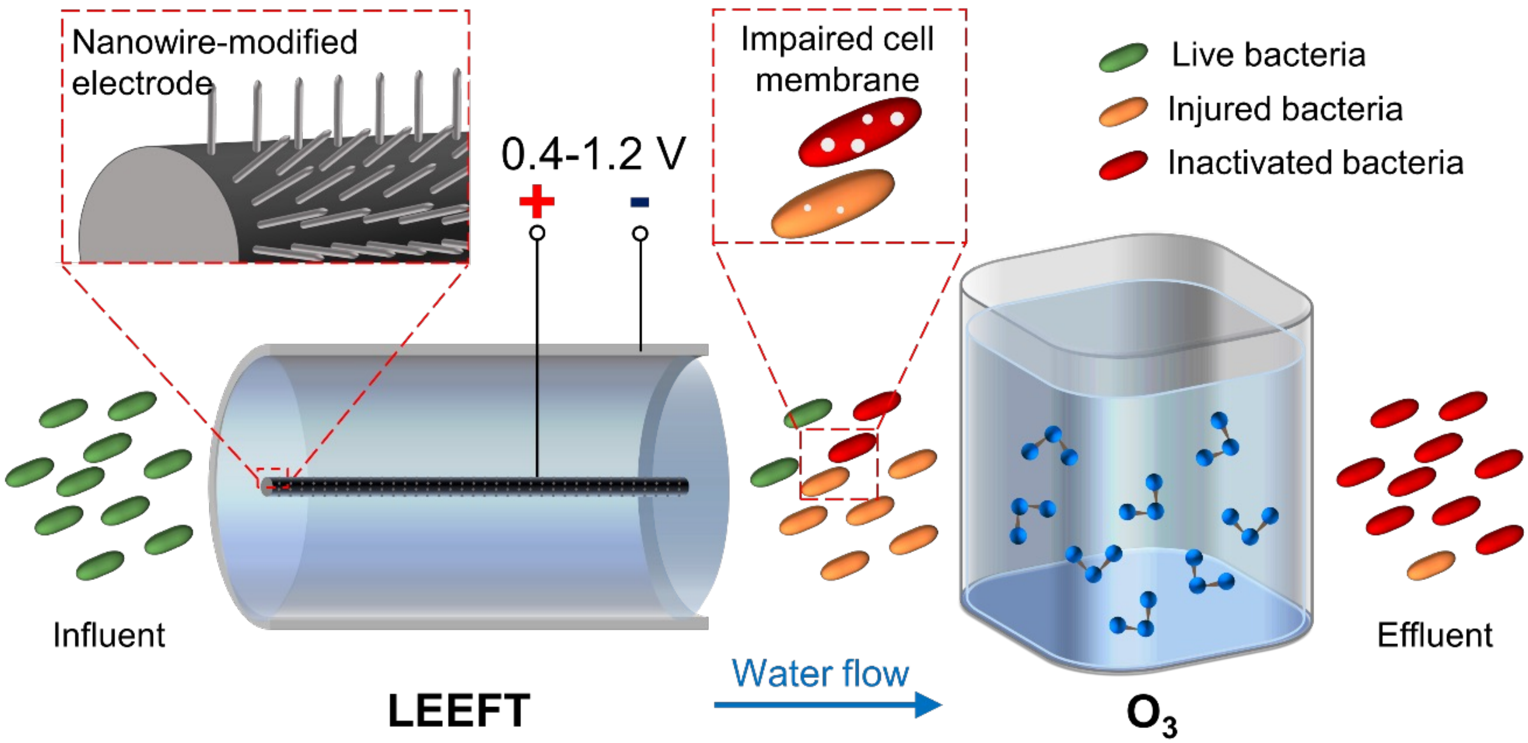






J. Zhou, et al. Environ. Sci. Nano. 2020, 7 (2), 397-403

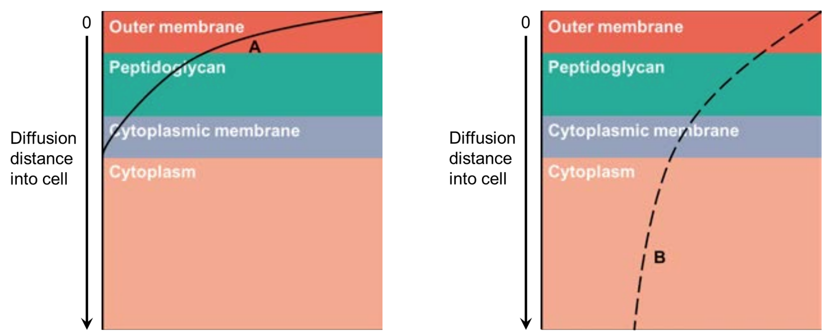
LEEFT – Ozone



J. Zhou, et al. Environ. Sci. Technol. 2020, 54, 21, 14017–14025

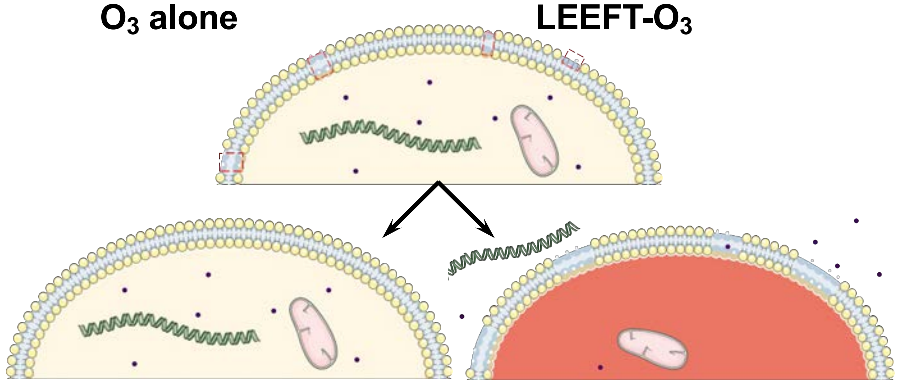
LEEFT-Ozone

- Mechanism



O_3 alone **LEEFT-O_3**

I: LEEFT could **enhance** the **permeability** of the cell membrane, so to **promote** the **diffusion** of O_3 into the cells to oxidize **intracellular** substances.
→ LEEFT makes O_3 more efficient.



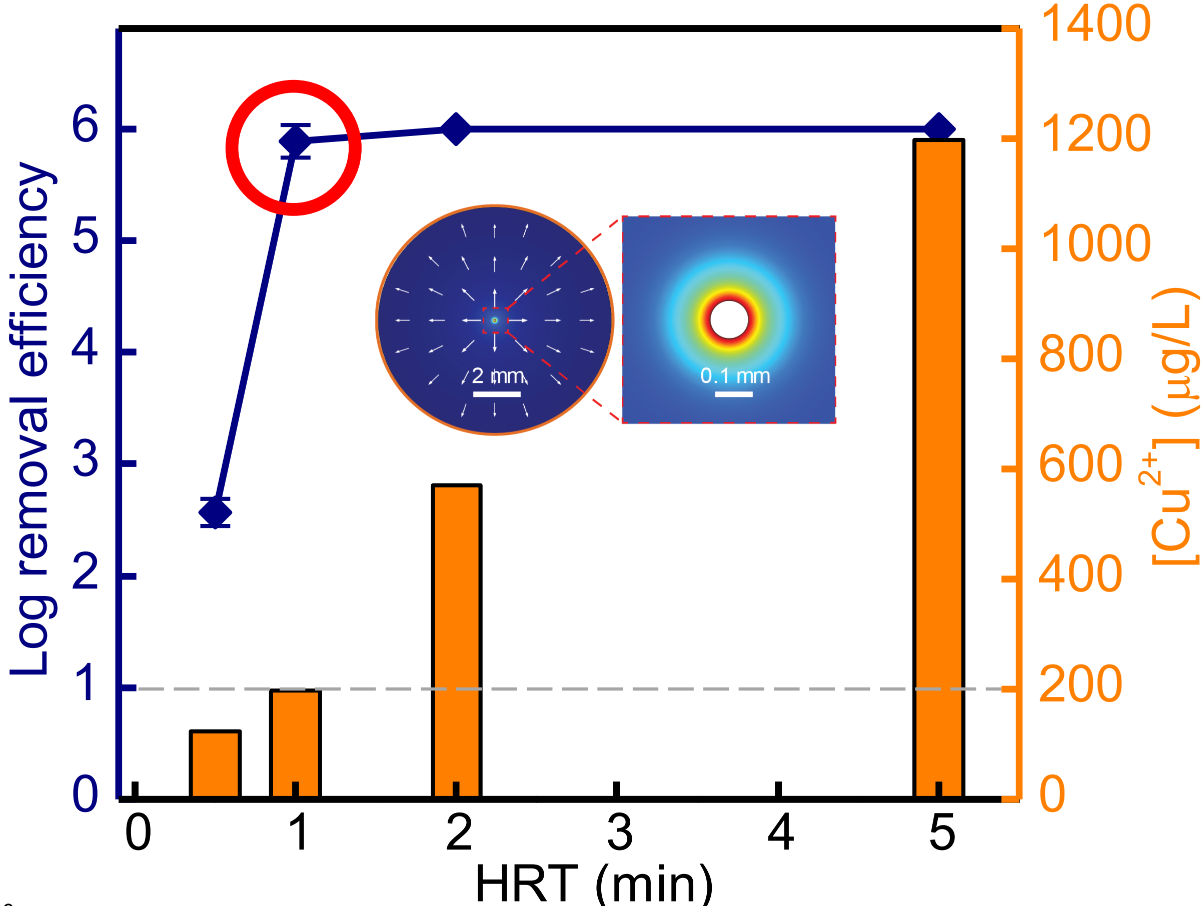
LEEFT alone
Resealed & alive

LEEFT-O_3
Inactivated

II: O_3 could **inhibit** the **resealing** of pores induced by **reversible electroporation** during LEEFT.
→ O_3 makes LEEFT more efficient.

J. Zhou, et al. Environ. Sci. Technol. 2020, 54, 21, 14017–14025

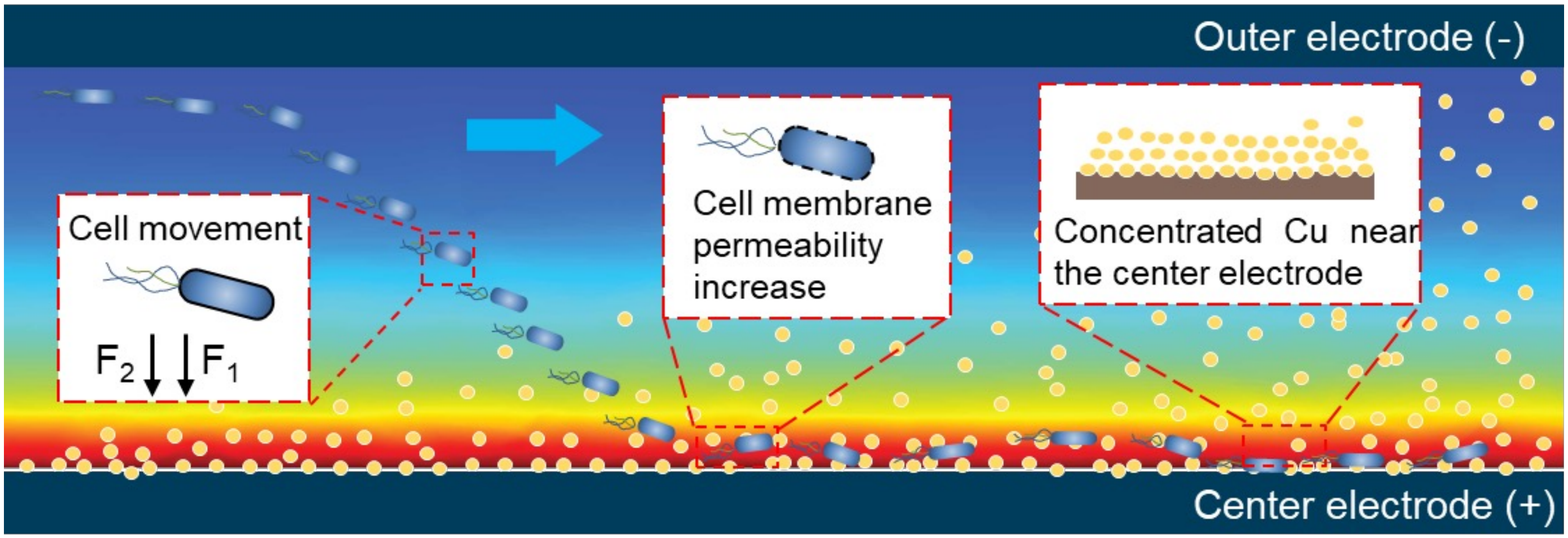
LEEFT – Cu



J. Zhou, et al. Environ. Int.. 2019, 128, 30-36

LEEFT-Cu

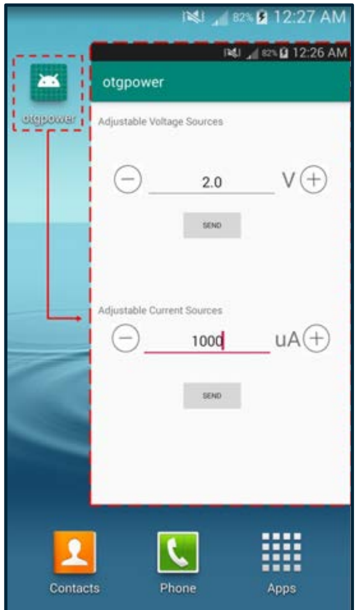
- Mechanism



LEEFT-Cu Powered by TENGs

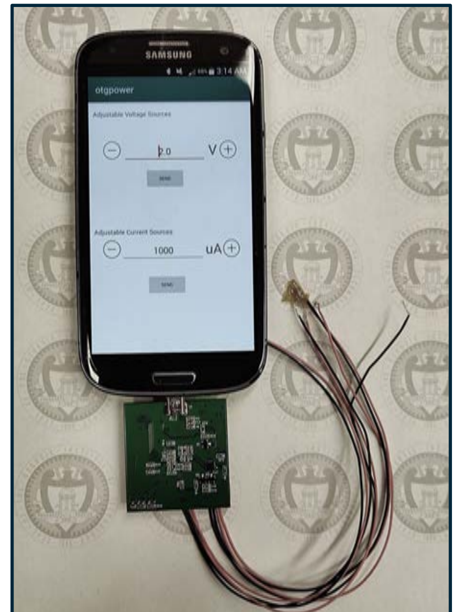
W. Ding#, J. Zhou#, et al. Adv. Energy Mater. 2019, 9 (27), 1901320

LEEFT-Cu Powered by Cell-Phones



App

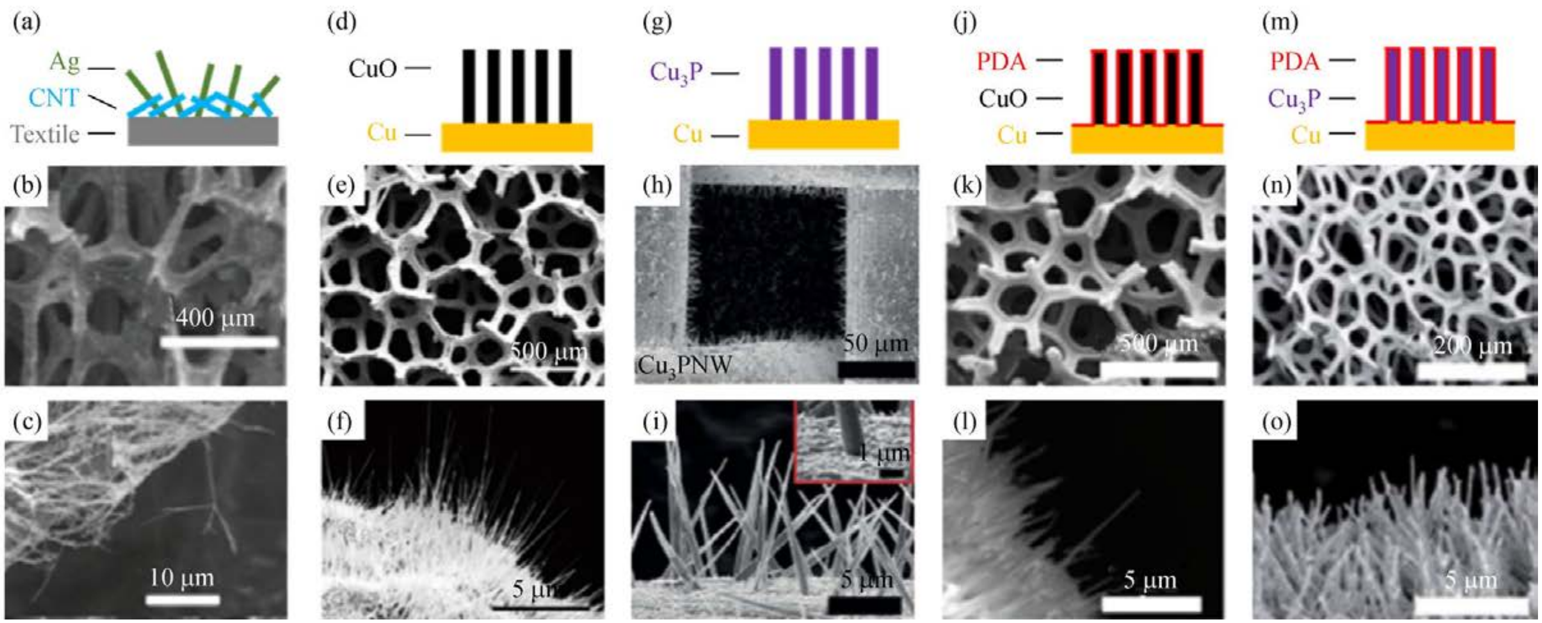
OTG hardware



Integrated system

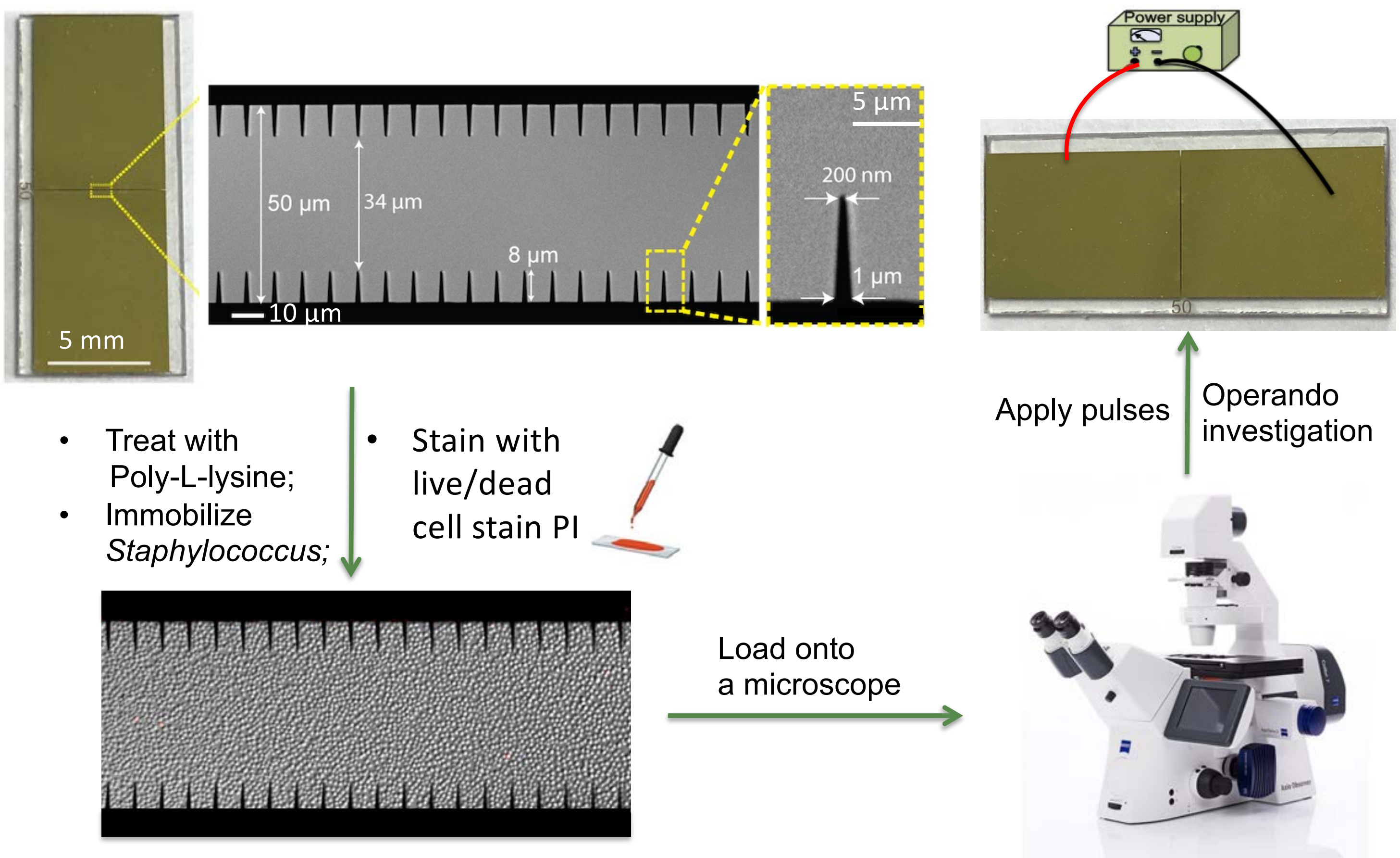
J. Zhou et al. npj *Clean water.* 2020, 3 (1), 1-9

LEEFT Electrodes



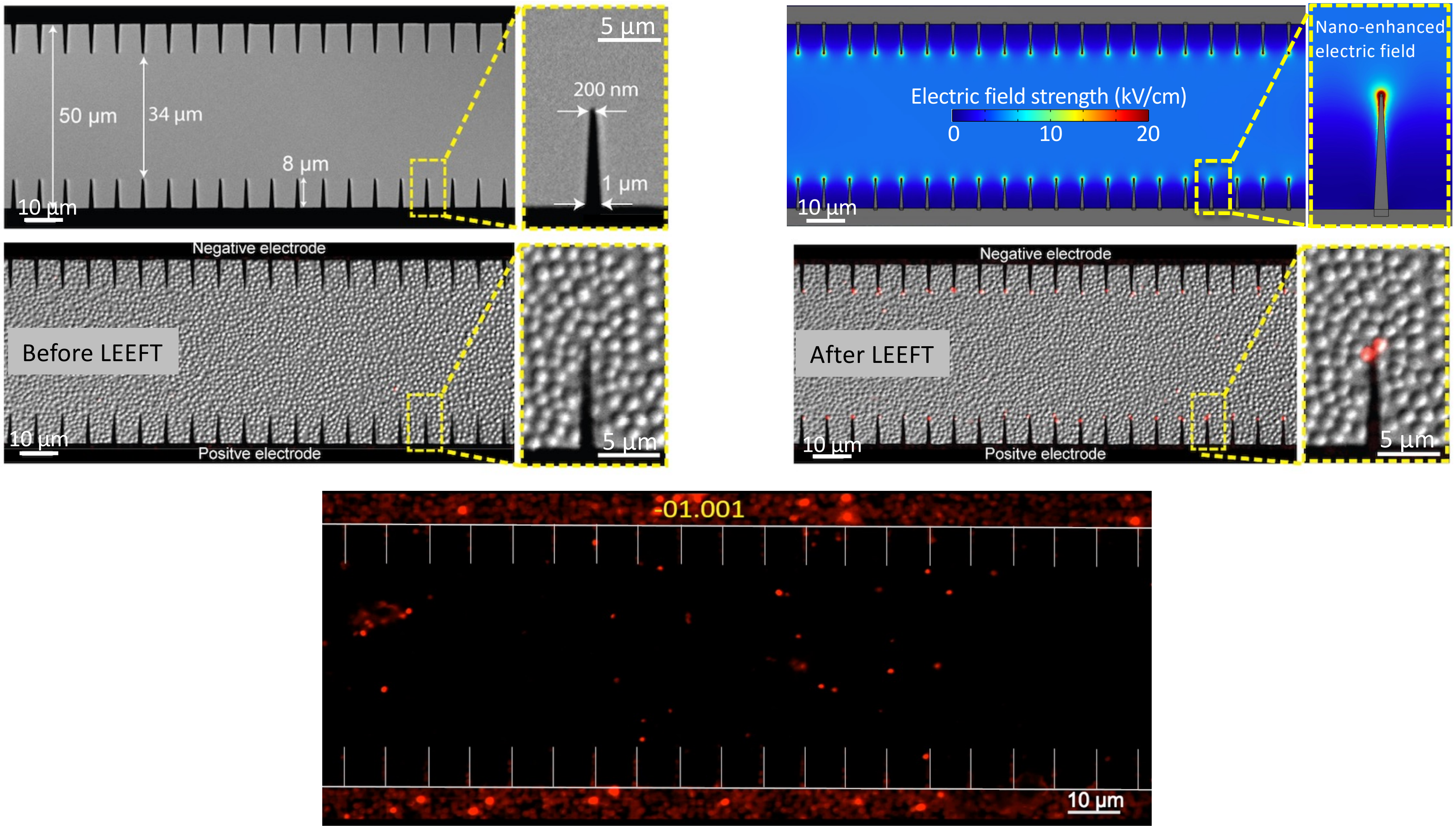
J. Zhou et al. Journal of Materials Chemistry A, 2020, 8, 12262-12277

Visualization of LEEFT



T. Wang, et al. Nano Letters, 2022, 2: 860-867

Visualization of LEEFT



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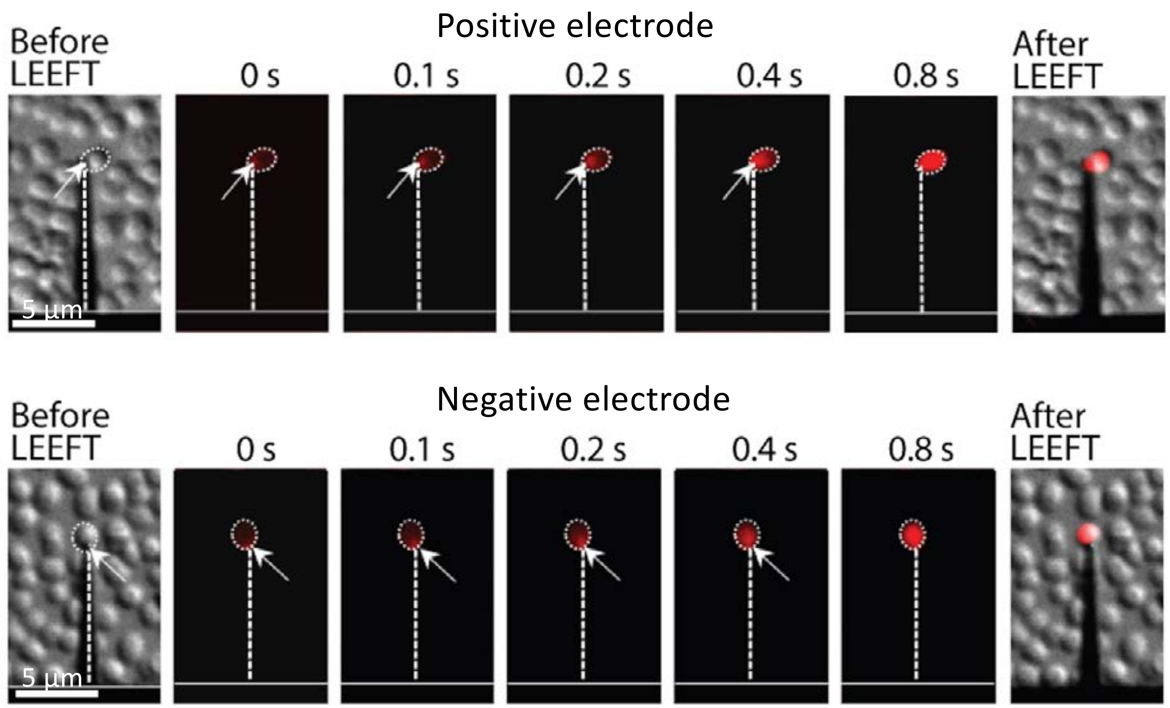
Visualization of LEEFT



- Cell membrane damage occurs at the nanowedge tip, where the nano-enhanced electric field has the highest strength.

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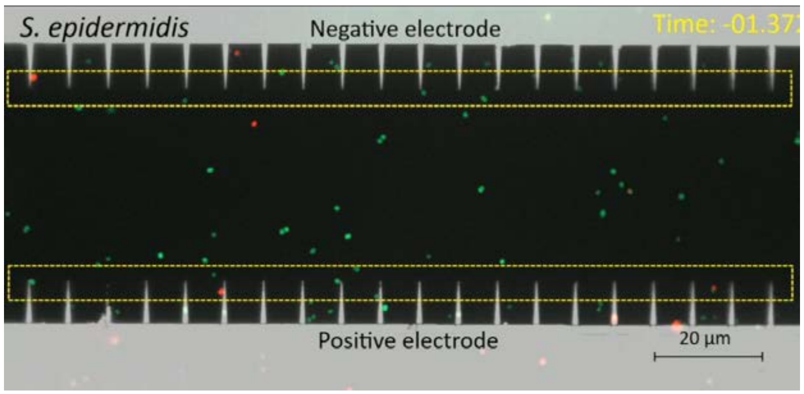
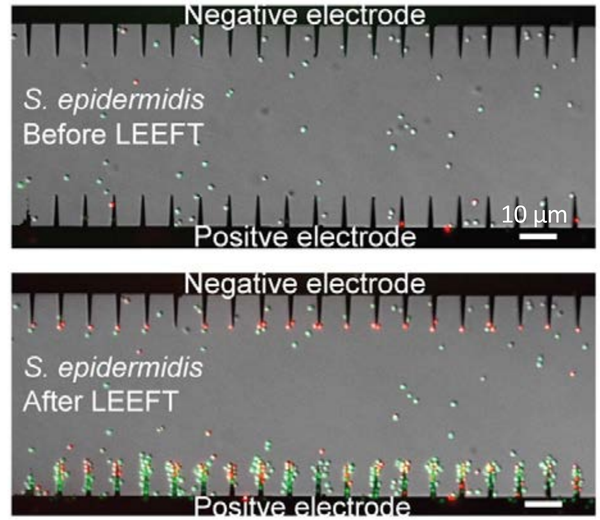
Visualization of LEEFT

LEEFT: 18 V/2 μs pulse width/100 μs period





- Free-moving cells are attracted to nanowedge tips on both electrodes and then get inactivated.
- Combination of both electrophoretic force and dielectrophoretic force.

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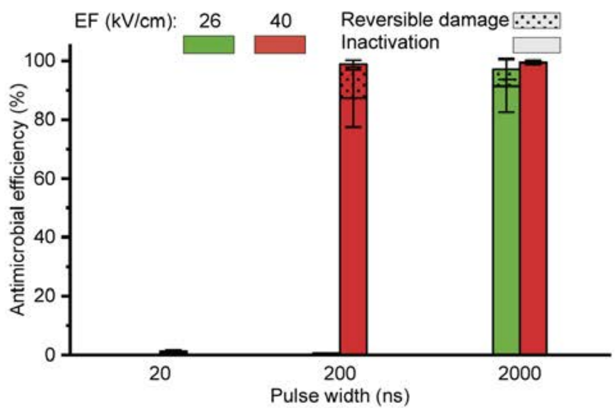
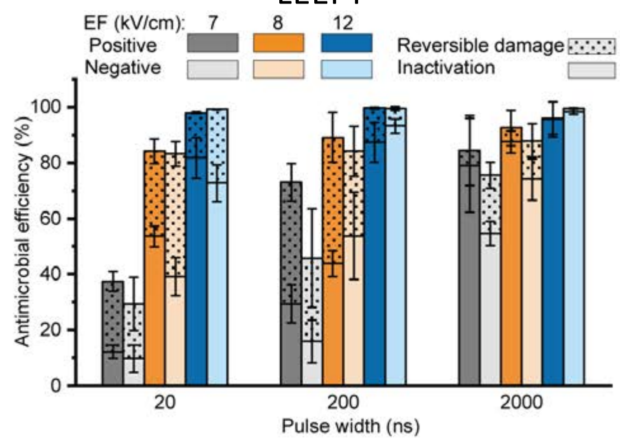
Nanosecond LEEFT

CEFT (no nanowedges)

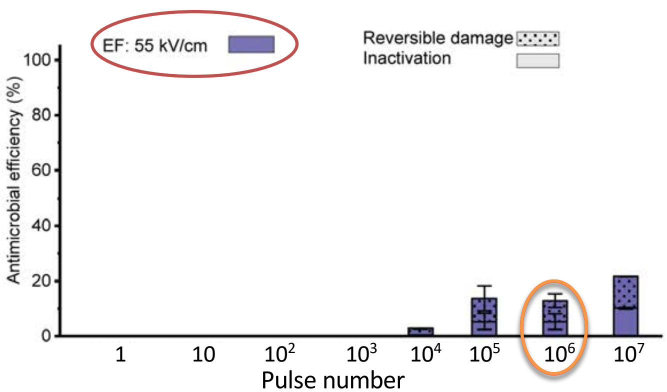


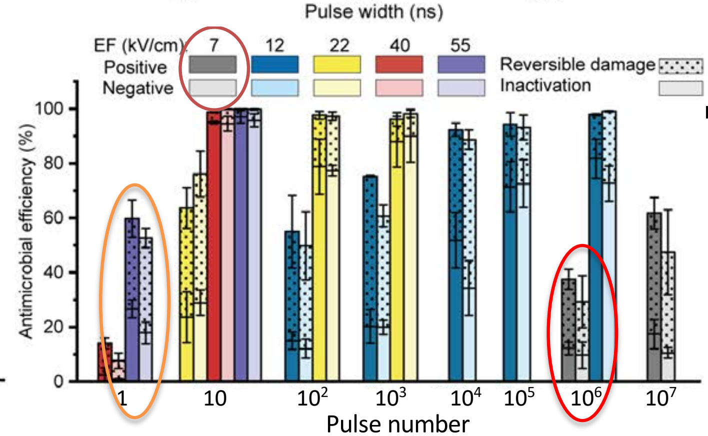
LEEFT



- Antimicrobial efficiency:

  2000 ns pulses → 20 ns pulses
  - CEFT: drops dramatically.
  - LEEFT: decreases slightly.



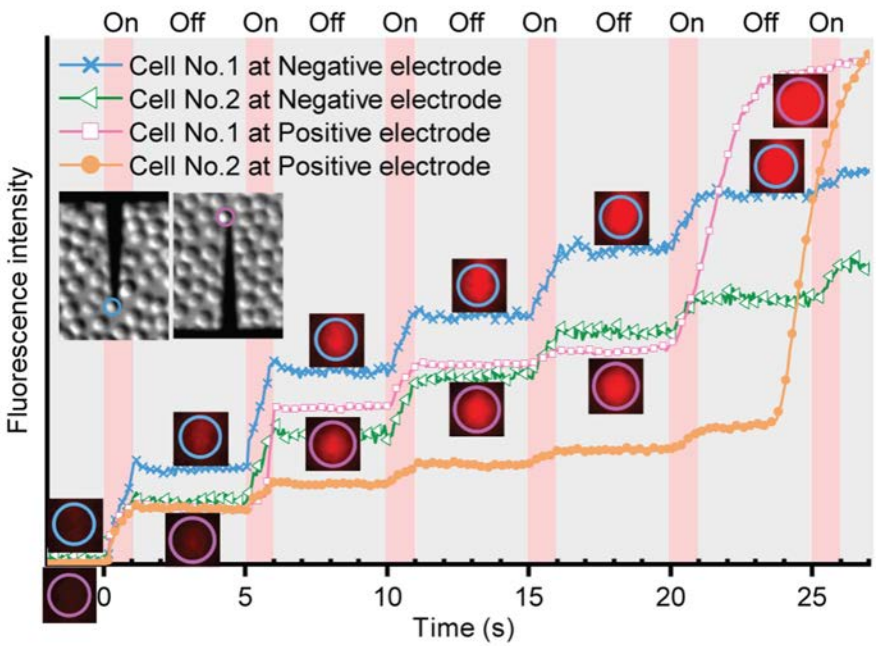


- 20 ns pulses: LEEFT shows a significant advantage
  - EF is reduced by 8 times;
  - Pulse number is reduced by 10^6 times.

T. Wang, et al. In revision.

Operando Mechanism Study of LEEFT

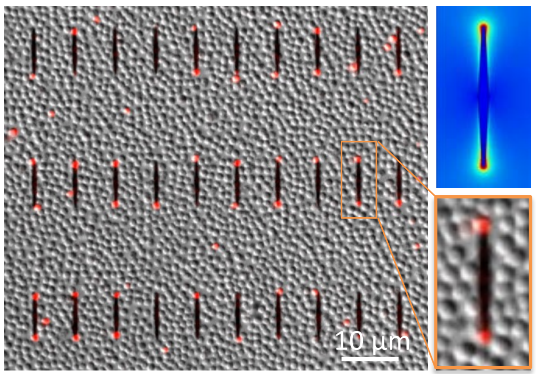
- Reversible electroporation is quick pore closure after the electric field is removed – a unique property of electroporation.
- Quick pore closure under 20 ns pulses at 12 kV/cm.

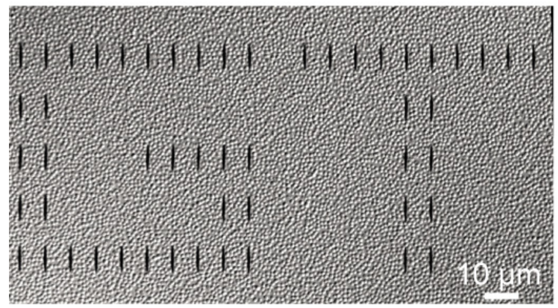


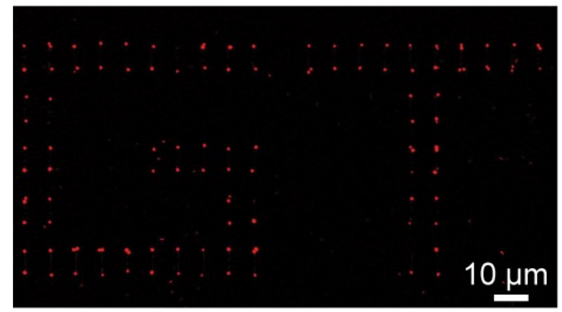
The ultrafast bacteria inactivation is induced by electroporation.

T. Wang, et al. In revision.

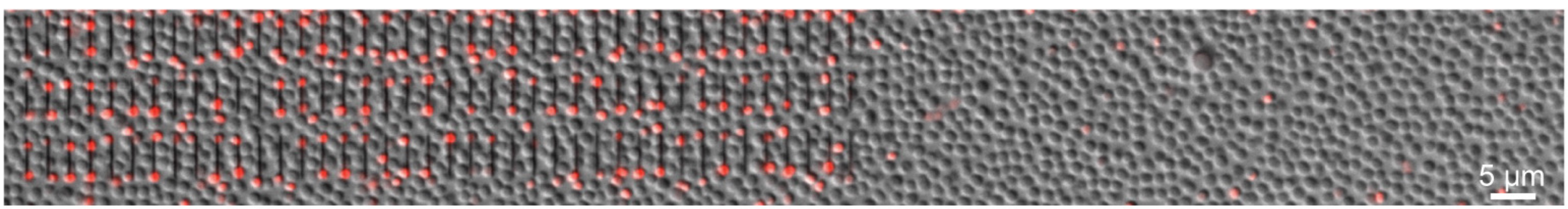
LEEFT with Non-connected Nanowedges







- The nanowedges not connected to the electrodes but between two electrodes: achieve EF enhancement and induce ultrafast bacteria inactivation.



- Densely packed smaller nanowires: a potential antimicrobial surface.

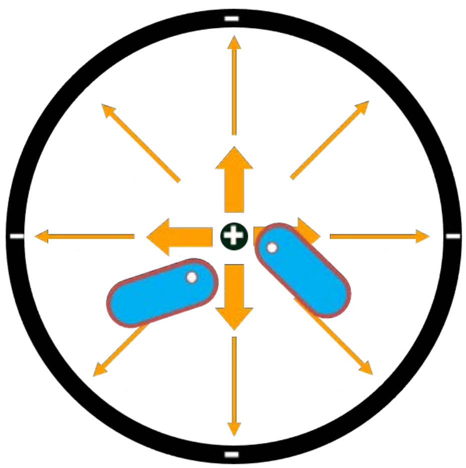
T. Wang, et al. In revision.

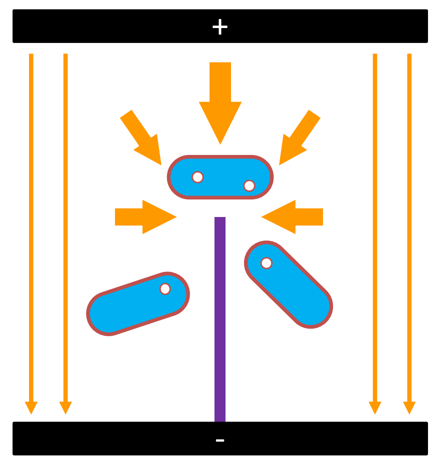
Applications of LEEFT

- A transformative water disinfection method
  - **High** microbial inactivation **efficiency**
  - **Broad-spectrum** effective to all pathogens
  - **Fast** treatment process
  - **Low** capital, operational, and maintenance **cost**
  - **No impact on** the physical and chemical property of the **treated water** (i.e., neither generating DBPs nor releasing toxic metals nor increasing the corrosivity)
  - Operate on electricity **without** any **chemical** consumption
  - **No overtreatment** concerns
  - **No secondary pollution** in terms of odor, sound, or light
  - **Easy to operate** and possible for automatic operation
  - Completely **safe** to operators and nearby community

Applications of LEEFT

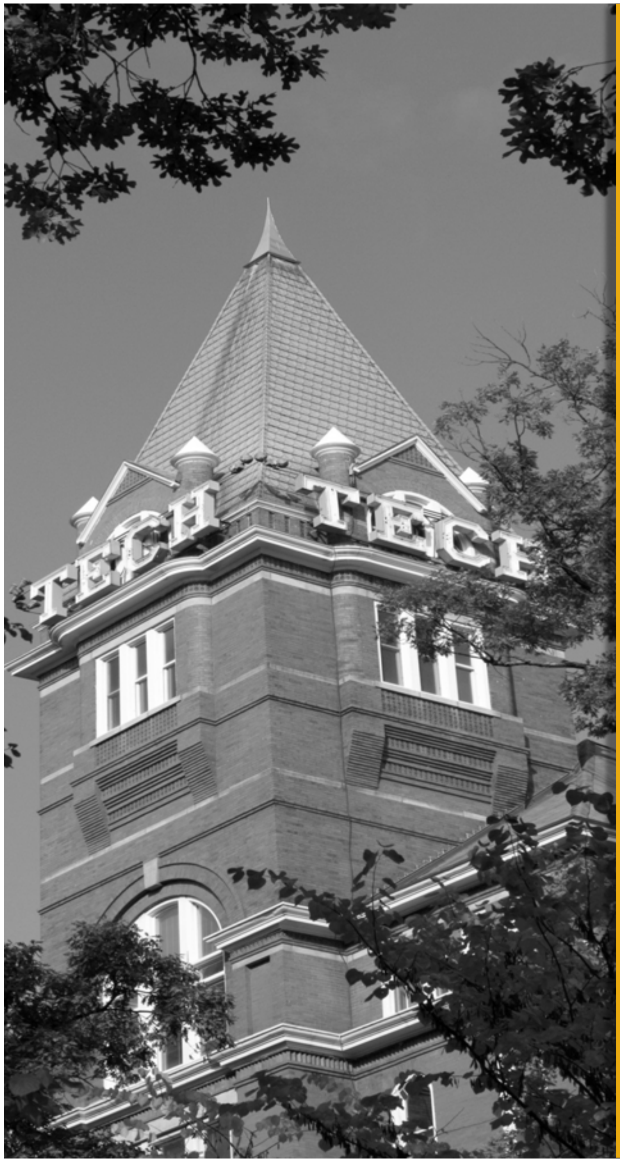
- Other applications
  - Liquid food pasteurization
  - Algae-bloom control
  - Air disinfection
  - Anti-microbial surface





Take-Home Message

- Disinfection is important
- We still need better technologies for disinfection
- Locally enhanced electric field treatment (LEEFT) is a promising candidate for next-generation disinfection



Thank you!

Xing Xie

October 5, 2022

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