Self-Propelled Swimming Microrobot Using Electroosmotic Propulsion and Biofuel Cell

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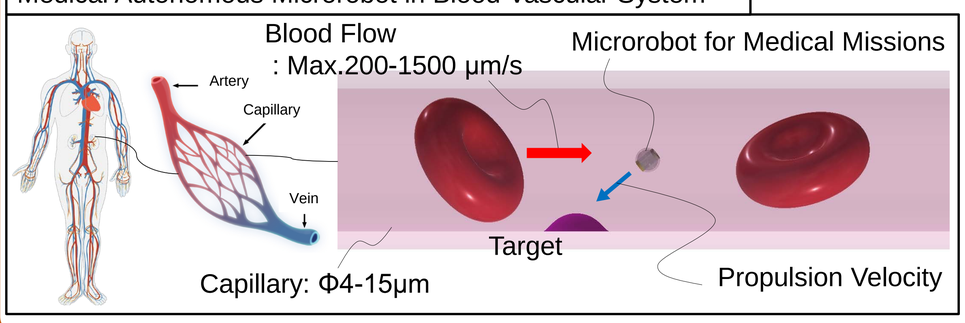
Smaller One is Faster ! New Micro Swimmer

For Future Medical Microrobotics



To realize mobile microrobots inside a human body ...

Required Technology (WBS): Propulsion, Energy Supply, Control, Navigation, Communication, Manipulation, (etc)

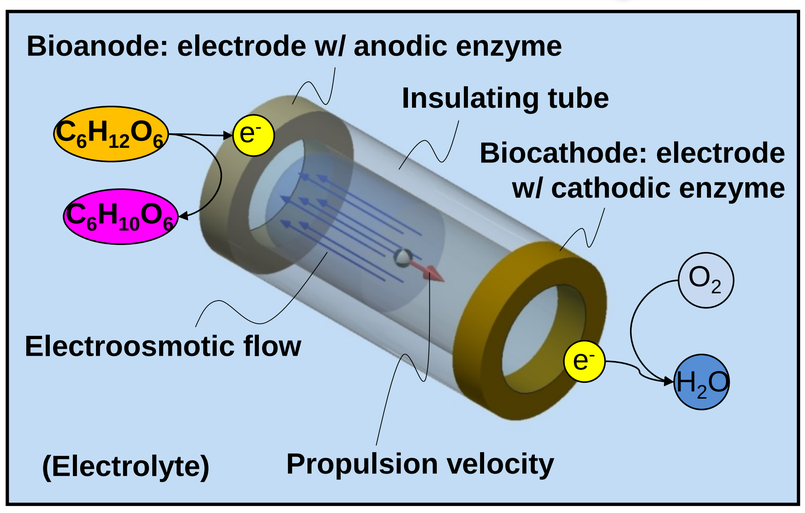
<< 1st challenge : propulsion counter to capillary flow >>
Requirements: Velocity ≥ 200 μm/s and Size ≤ 10 μm.

Prior Propulsion Methods	Velocity (1-10 μm)	Energy Supply	Other Issues
External-Fields (Magnetic, ...)	~10 μm/s	OK	Large Footprint
Microorganism (MC-1, ...)	~100 μm/s	Unknown	Biocompatibility, Durability, ...
Catalytic (Phoretic Flow)	~1 μm/s	NG (H_2O_2)	
Catalytic (Bubble)	~1000 μm/s	NG (H_2O_2)	Large Bubbles, Toxicity (H_2O_2), ...

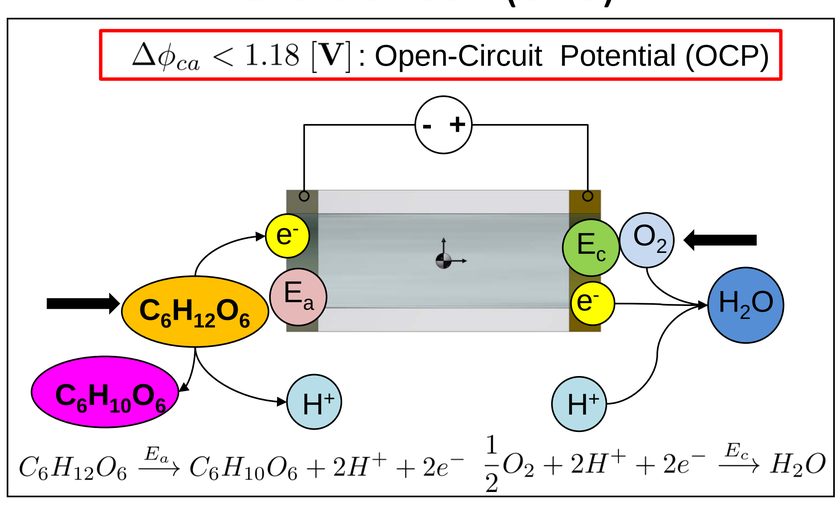
Not enough

New propulsion and energy supply methods are required !

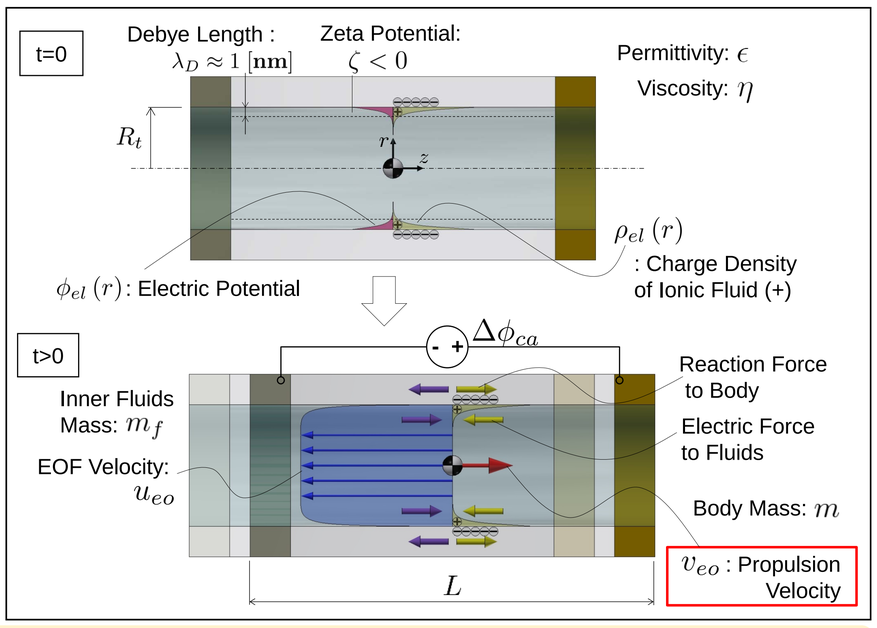
New Microrobot Concept!



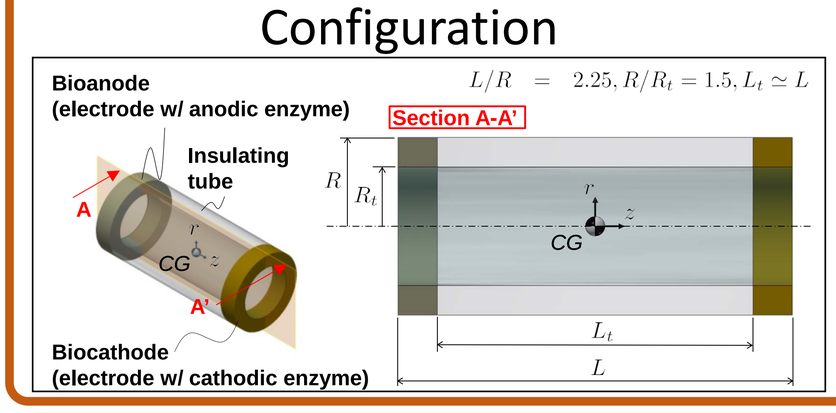
Biofuel Cell (BFC)



Electroosmotic Propulsion (EOP)



Configuration



Theoretical EOP Velocity

Electric Field : $E = -\Delta\phi_{ca}/L \quad (L_t \simeq L)$

Relative EOF Velocity : $u_{r,eo} = \mu_{eo}E \quad (\mu_{eo} = \epsilon\zeta/\eta)$, $u_{eo} - v_{eo} = -u_{r,eo}$

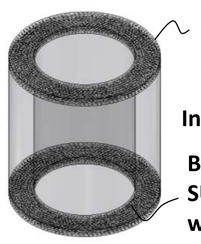
Momentum conservation : $mv_{eo} + m_f u_{eo} = 0$

$$v_{eo} = -\frac{1}{1+\frac{m}{m_f}} \cdot \frac{\epsilon\zeta}{\eta}\frac{\Delta\phi_{ca}}{L}$$

- BFC generates an OCP, which cause EOF.
- Its reaction force then propels the robot.
- Smaller one will be faster.
- This is suitable for microscale propulsion.

Microscale Prototype (~100μm)

Design

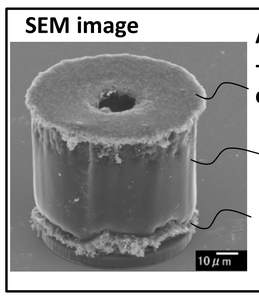


Bioanode : SU-8+metal-NPs w/anodic enzymes

Insulating tube : SU-8

Biocathode: SU-8+metal-NPs w/cathodic enzymes

Prototype

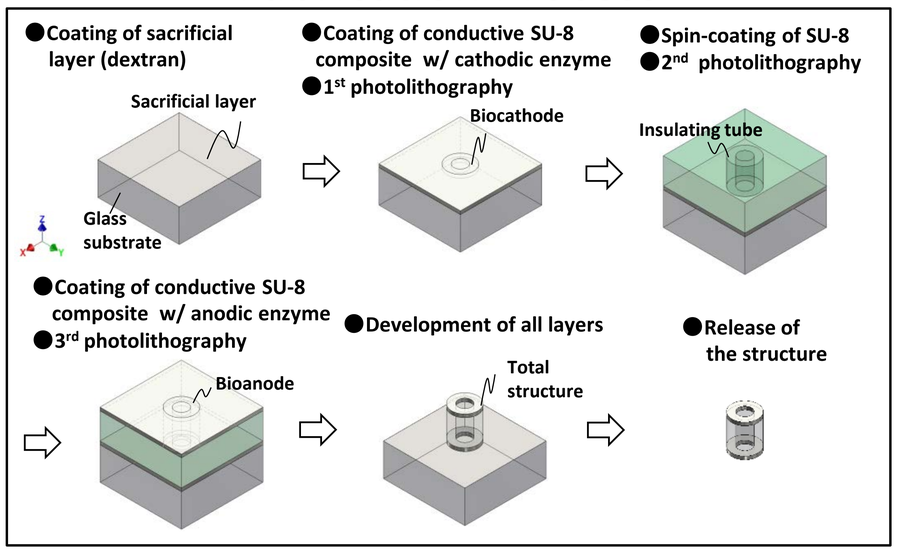


Ag-NPs w/GOx + SU-8 composite

SU-8

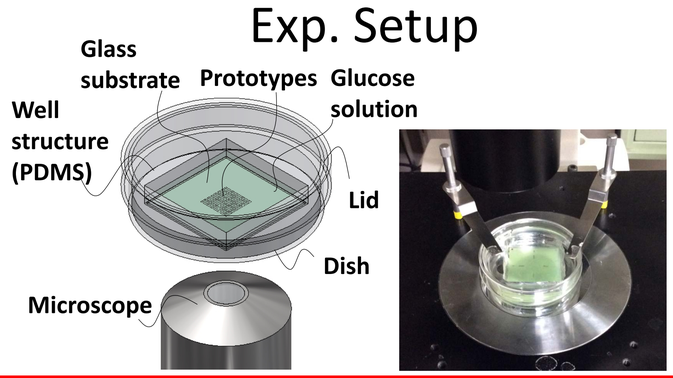
Ag-NPs w/ LAC +SU-8 composite

Fabrication Process

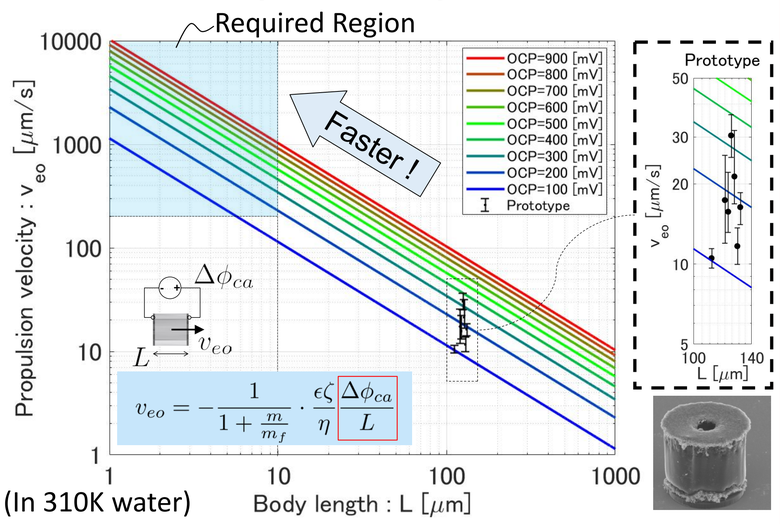


Feasibility Study

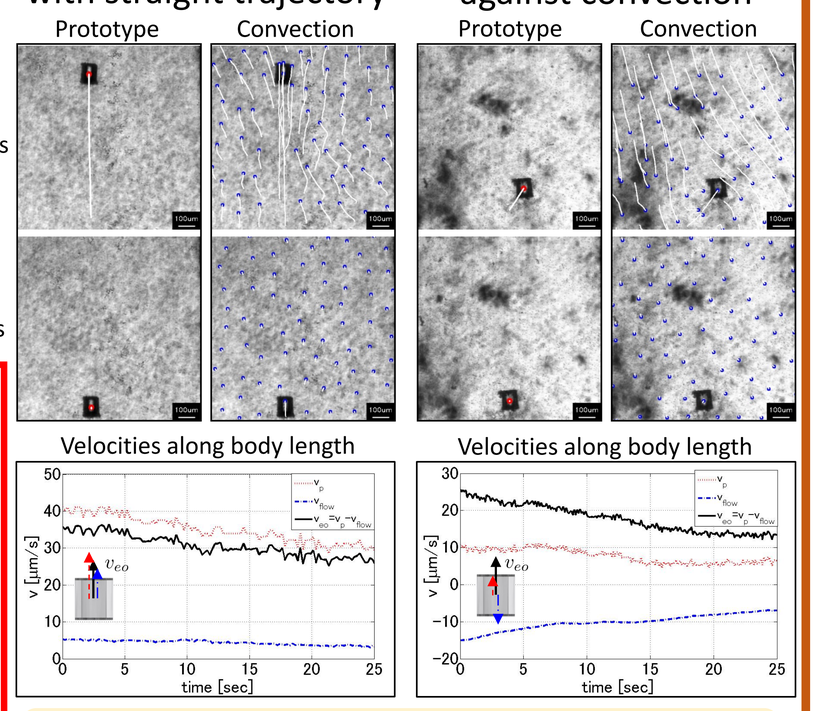
Exp. Setup



Theory and Experiments



Self-Propulsion in Glucose Solution



- Self-propulsions (max. 35 μm/s) of prototypes were observed.
- The velocities were within the theoretically expected range.

Conclusion

- We proposed the new concept by EOP and BFC.
- Smaller one will be faster theoretically.
- We confirmed the concept validity experimentally.

The concept will be a key component for future medical microrobotics.

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