On-chip electrochemical capacitors for self-powered IoT sensor nodes

Per Lundgren & Agin Vyas, Chalmers

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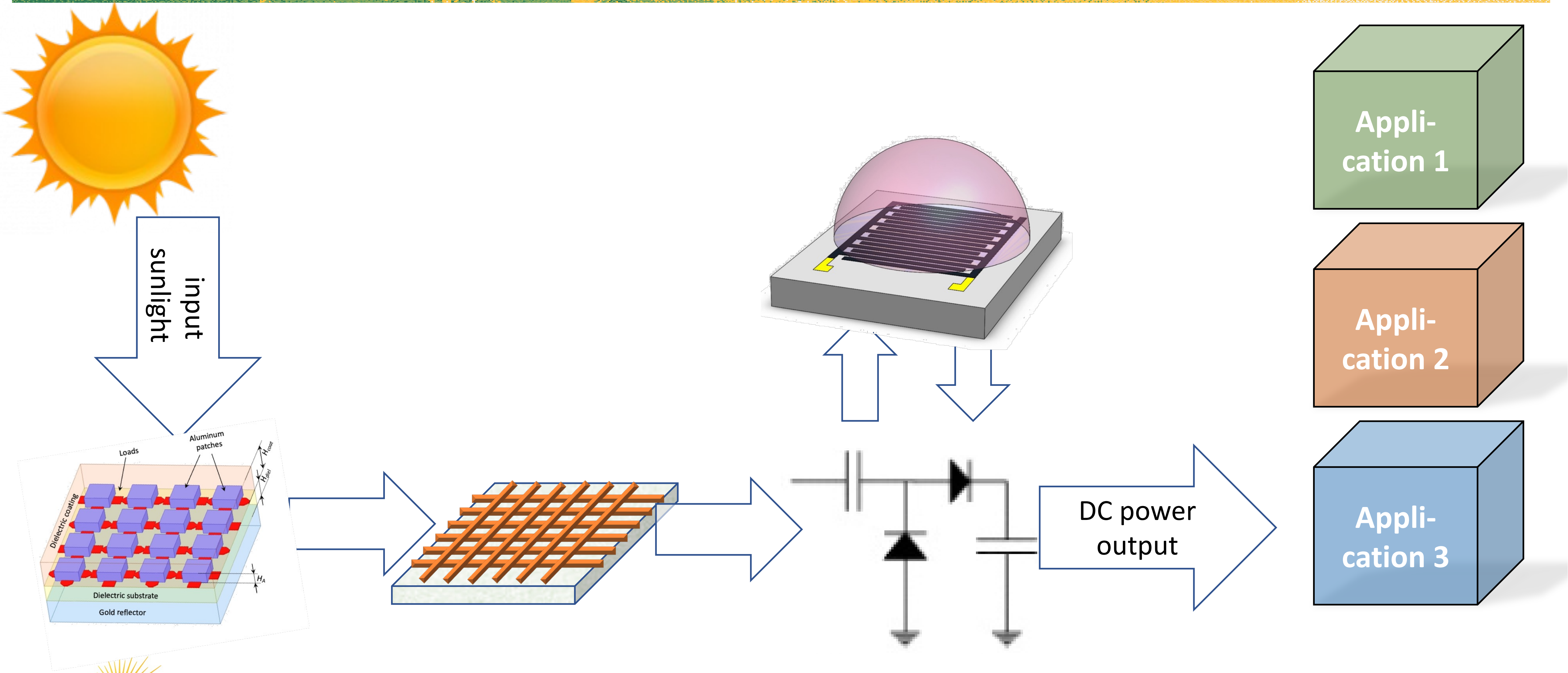
System structure for solar harvester



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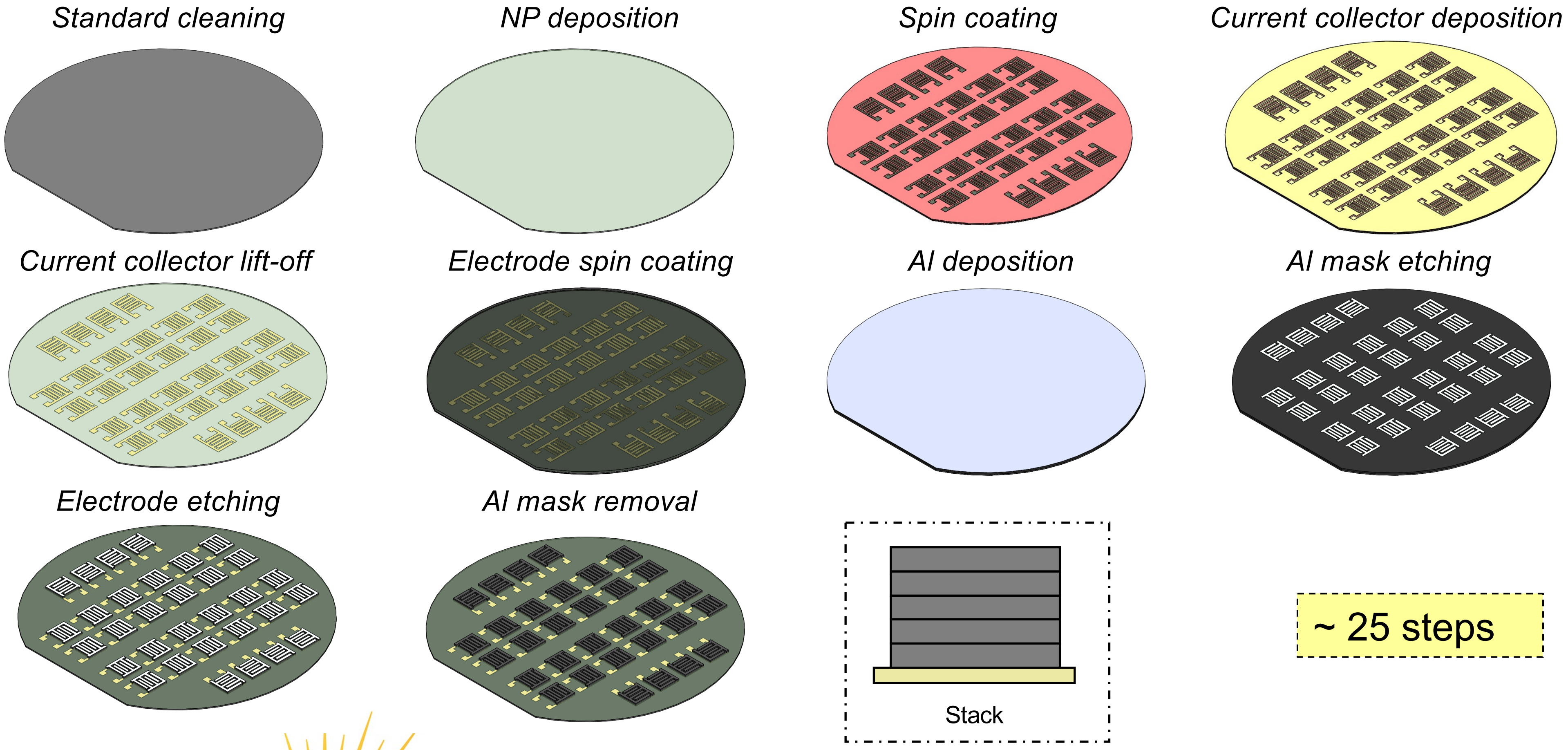
On-chip supercapacitor fabrication



Enhanced Electrode Deposition for On-Chip Integrated Micro-Supercapacitors by Controlled Surface Roughening, *ACS Omega 2020. DOI: 10.1021/acsomega.9b04266*

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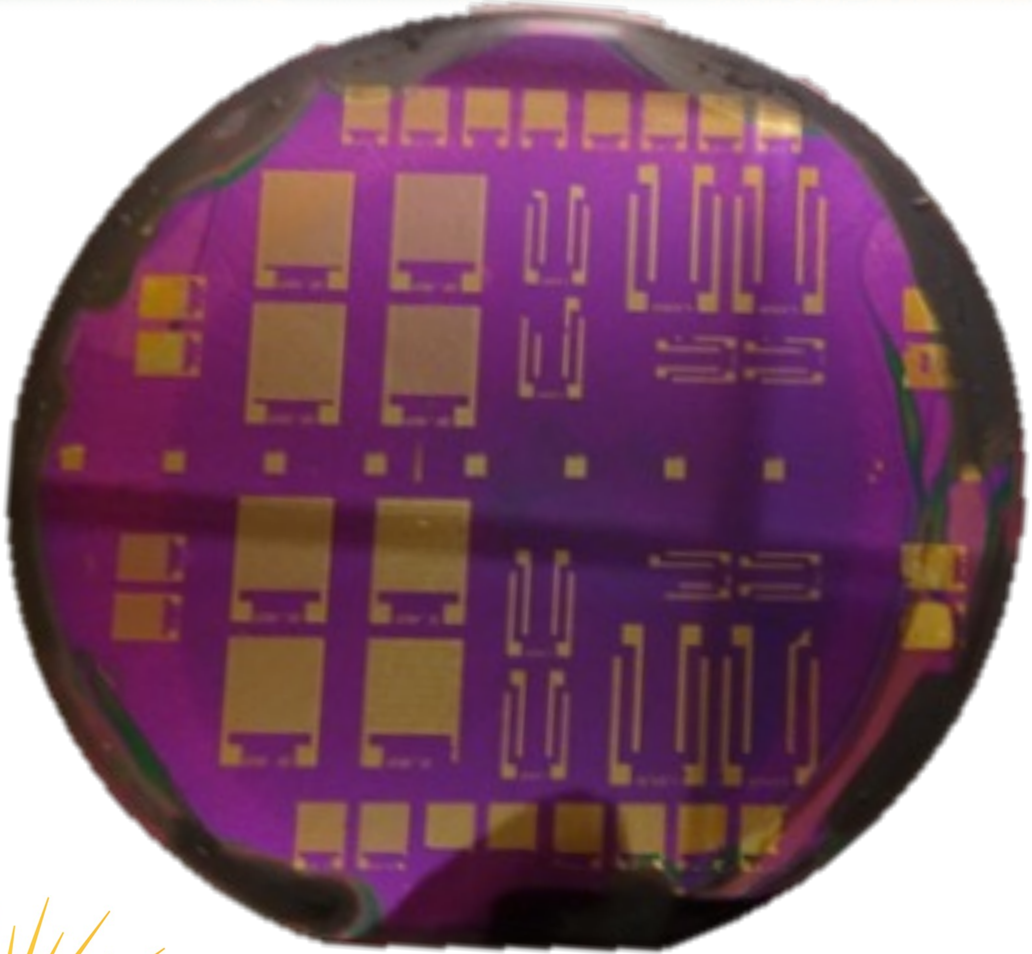

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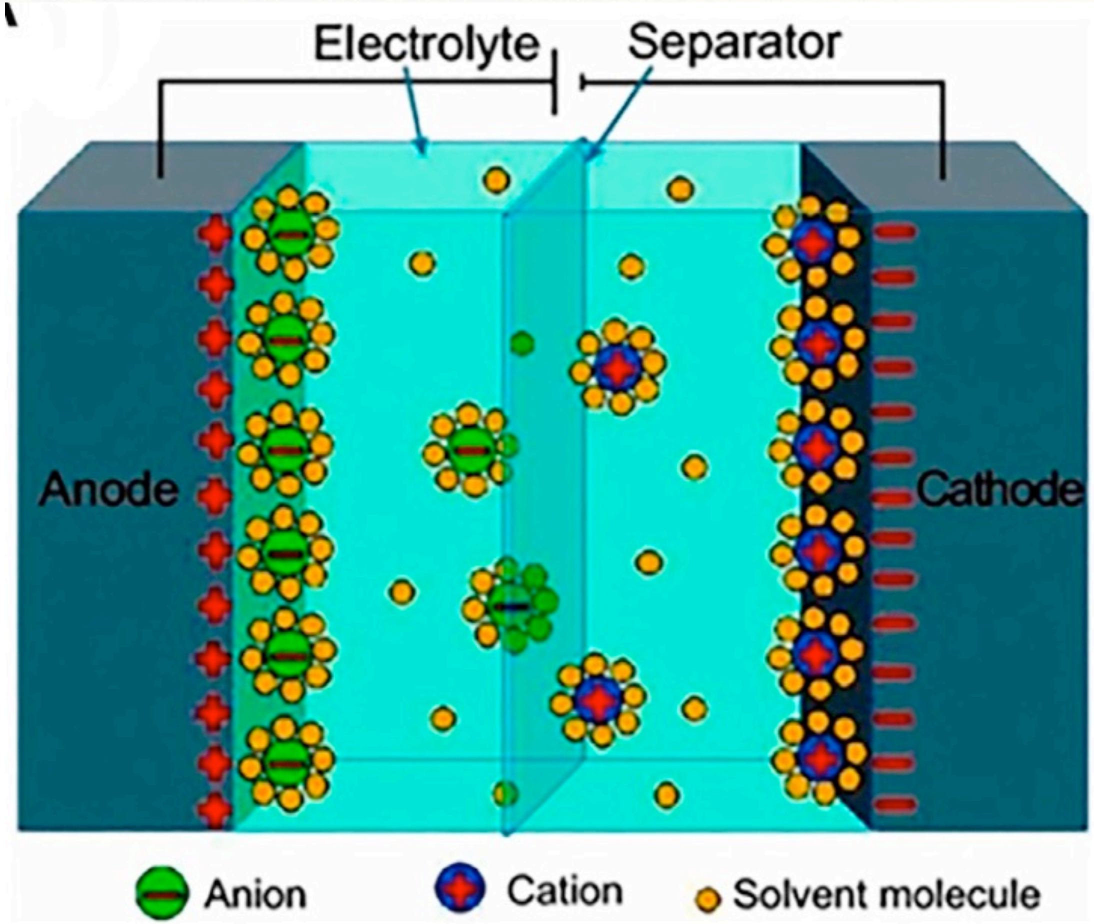
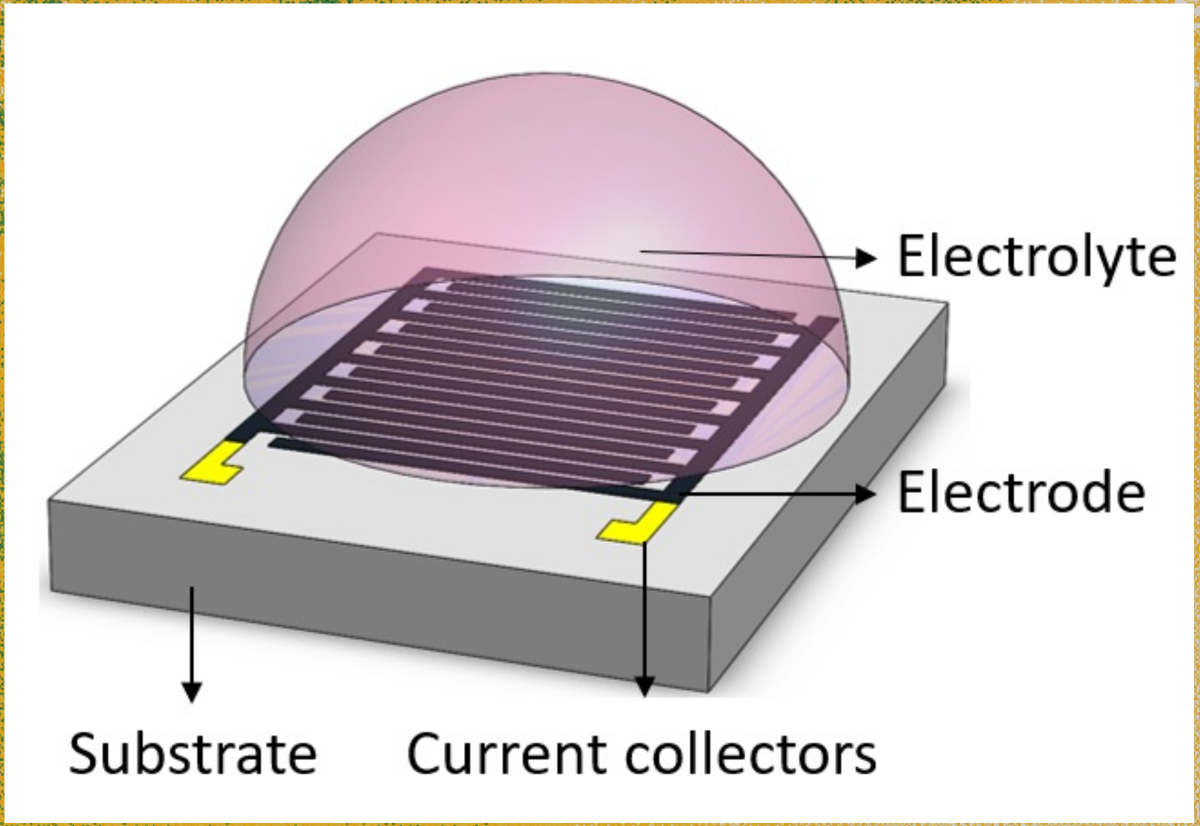


Sun X et al., (2022) Perspective on Micro-Supercapacitors.
Front. Chem. 9:807500. doi: 10.3389/fchem.2021.807500

The input intensity from the sun is 1 $kW \cdot m^{-2}$.

Assuming we can convert this to DC-power at very high efficiency -

what level of intermittencies can we manage using electrochemical energy storage?



State-of-the art maximum specific energy (per unit area) for electrochemical on-chip capacitors is (almost) in the order of…

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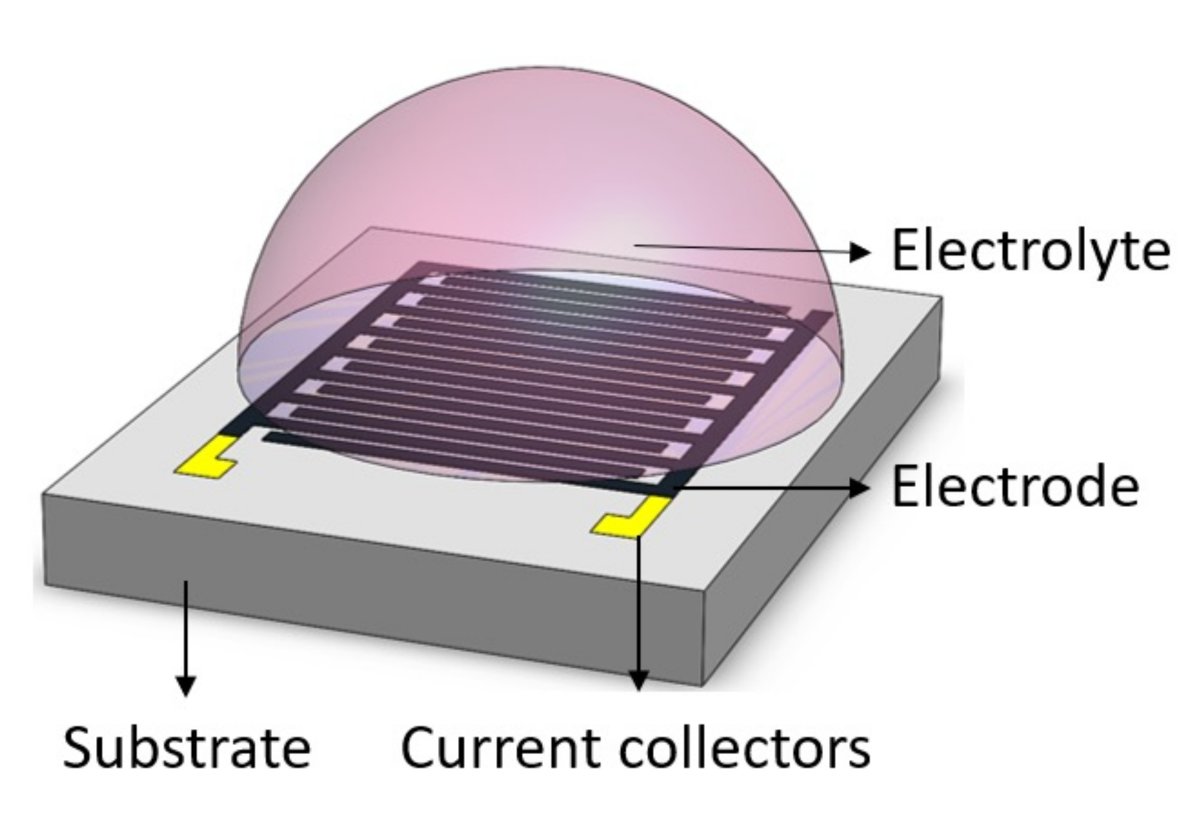

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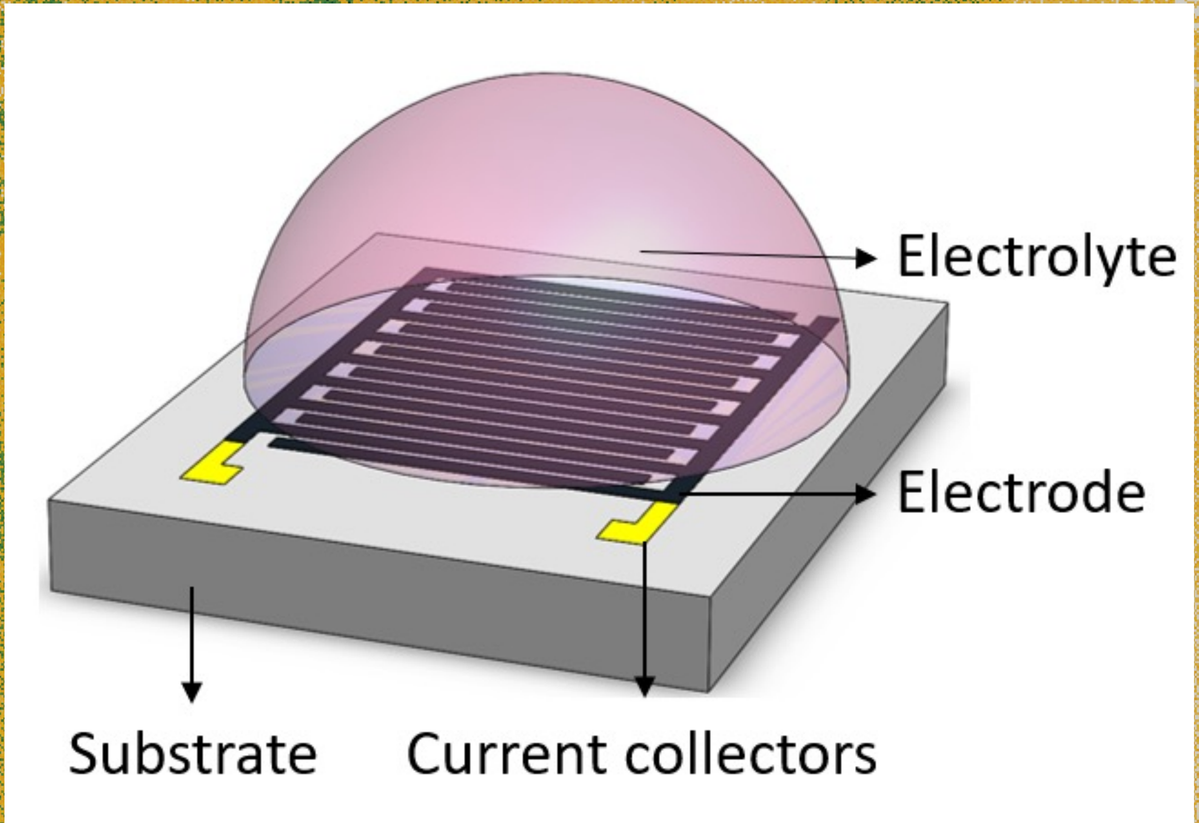
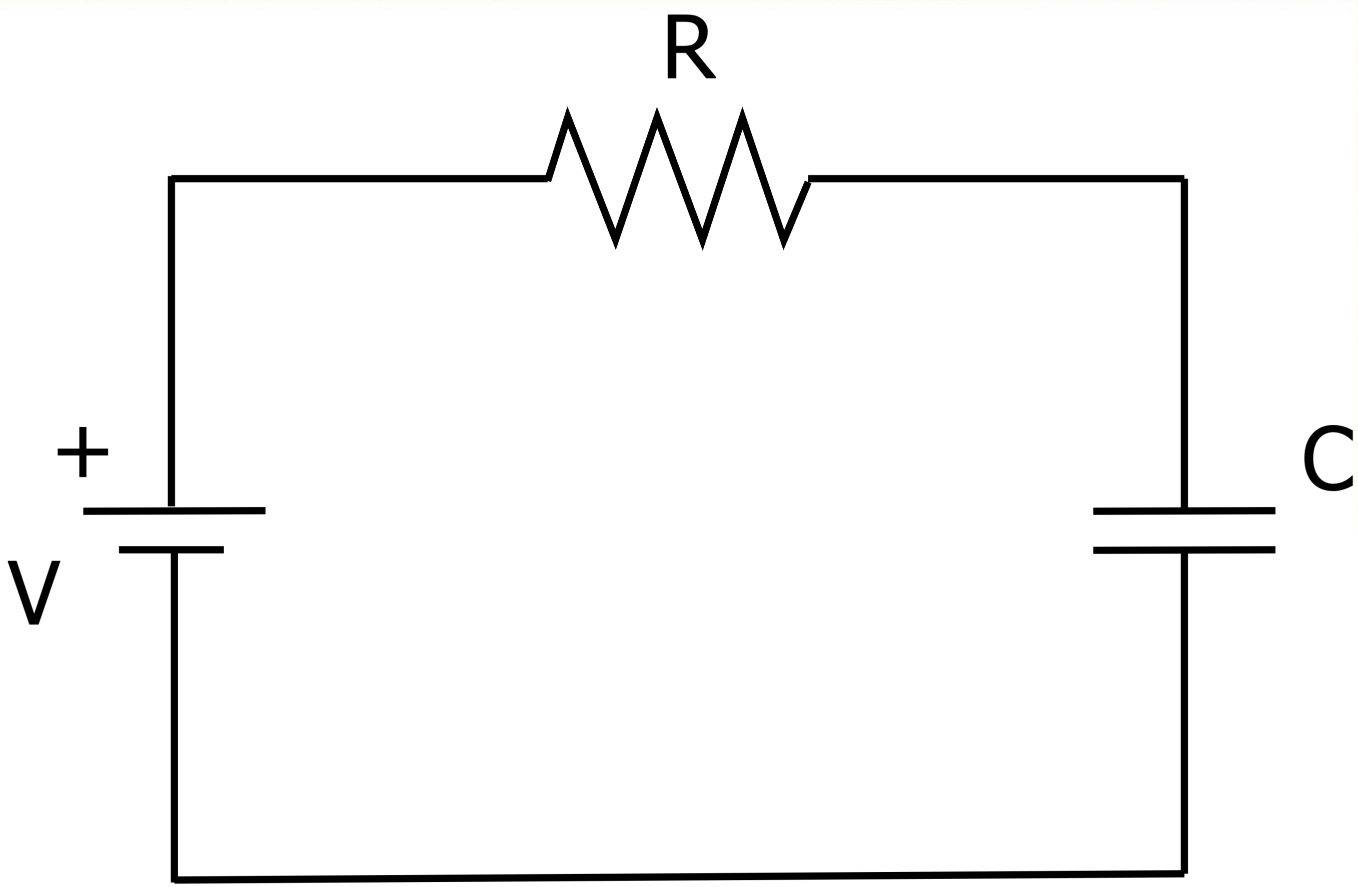


What we can provide using supercapacitors is smooth and stable power output at the level of 0,1 kW·m^{-2}, provided we have small enough variations in input power.

The curse of storing energy in a capacitor.

Should you charge as quickly as possible, or as slowly as you can for high efficiency?

$$E = \int_0^\infty V \cdot I \; dt$$



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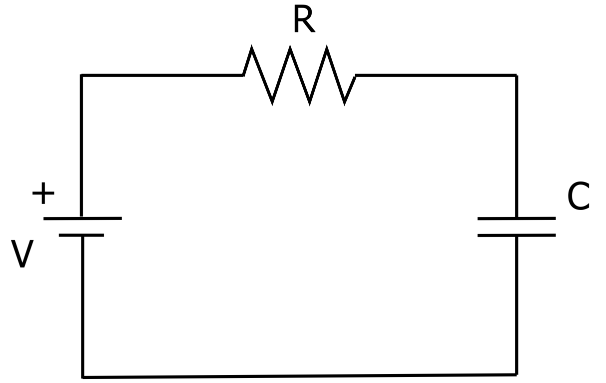
The curse of storing energy in a capacitor.

Energy delivered from the ideal voltage source with a step function.

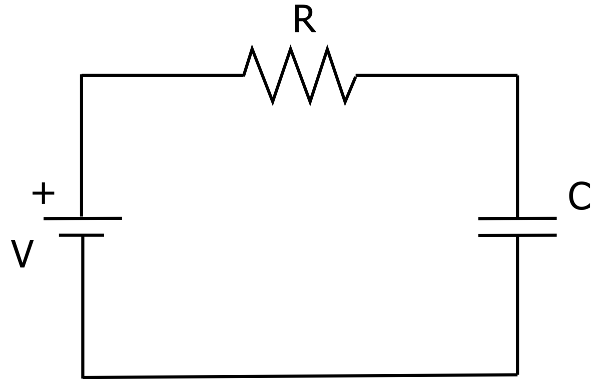
$$I(t) = \frac{V - V_c(t)}{R} = \frac{V}{R} - \frac{Q_c(t)}{R \cdot C} \quad \rightarrow \quad I(t) = \frac{V}{R} \cdot e^{-\frac{t}{RC}}$$



The curse of storing energy in a capacitor.

Energy delivered from the ideal voltage source with a step function.

$$E_V = V\int_0^{\infty} \frac{V}{R} \cdot e^{-\frac{t}{RC}}\, dt = \frac{V^2}{R}\left[-RC \cdot e^{-\frac{t}{RC}}\right]_0^{\infty} = V^2 C$$



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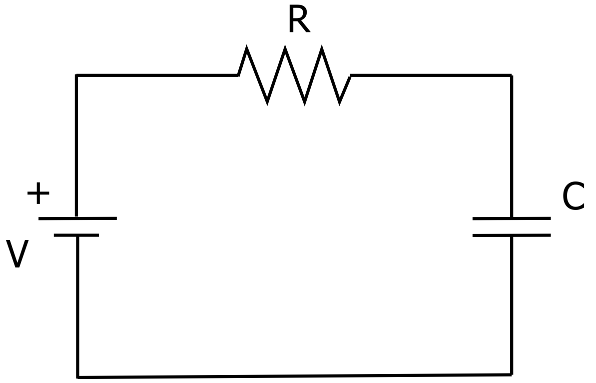
The curse of storing energy in a capacitor.

Energy dissipated in the resistor during charging.

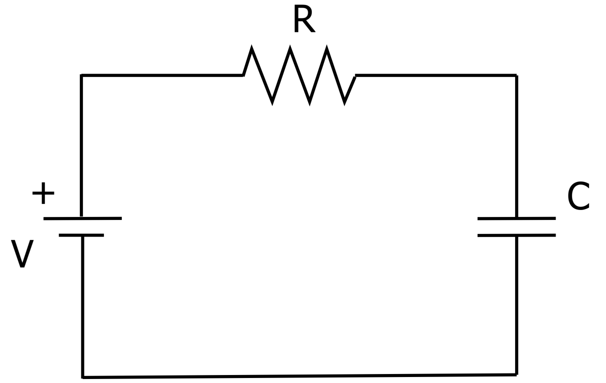
$$E_R = \int_0^{\infty} R \cdot I^2 \, dt = \frac{V^2}{R} \int_0^{\infty} e^{-\frac{2t}{RC}} dt = \frac{V^2}{R} \left[-\frac{RC}{2} \cdot e^{-\frac{2t}{RC}} \right]_0^{\infty} = \frac{V^2 C}{2}$$



The curse of storing energy in a capacitor.

Charging at constant voltage means losing 50% of the energy!

$$\frac{E_R}{E_V} = \frac{\frac{V^2C}{2}}{V^2C} = \frac{1}{2}$$

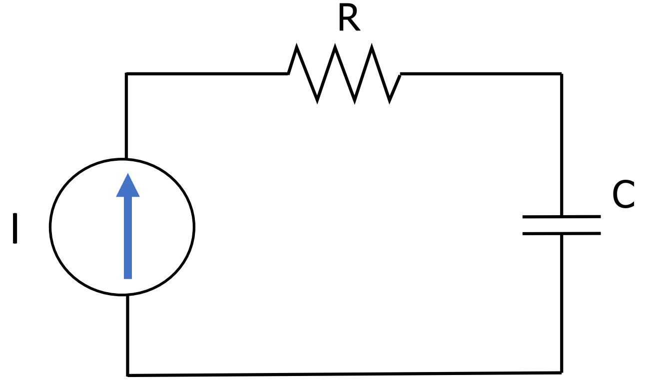


The curse of storing energy in a capacitor.

Energy delivered from the ideal constant current source.

For how long should we charge?

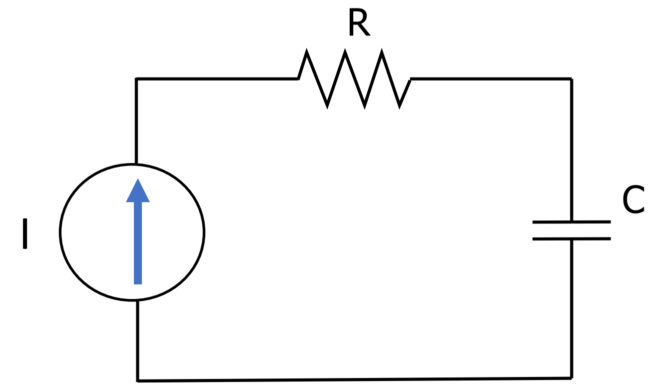
t_{stop} given by: $I \cdot t_{stop} = C \cdot V$



The curse of storing energy in a capacitor.

Energy delivered from the ideal constant current source.

$$E_I = \int_0^{t_S} (V_R + V_C) \cdot I \, dt = I \cdot \left(\int_0^{t_S} V_R \, dt + \int_0^{t_S} V_C \, dt \right)$$



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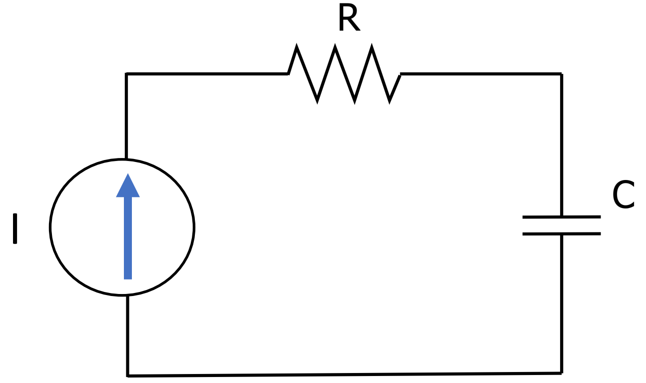
The curse of storing energy in a capacitor.

Energy delivered from the ideal constant current source.

$$E_I = R \cdot I^2 \cdot t_s + I \cdot \int_0^{t_s} \frac{I \cdot t}{C} dt = R \cdot I \cdot C \cdot V + \frac{I^2}{C} \cdot \frac{C^2 V^2}{2 \cdot I^2}$$



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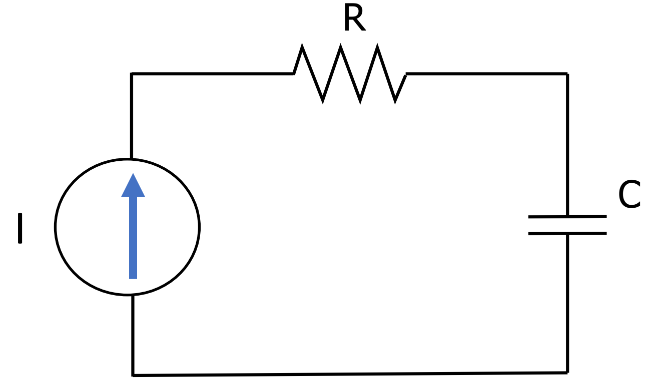
The curse of storing energy in a capacitor.

Energy delivered from the ideal constant current source.

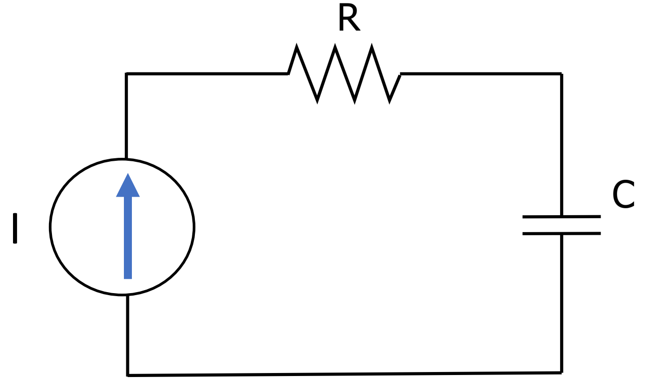
$$E_I = R \cdot I \cdot C \cdot V + \frac{C \cdot V^2}{2}$$

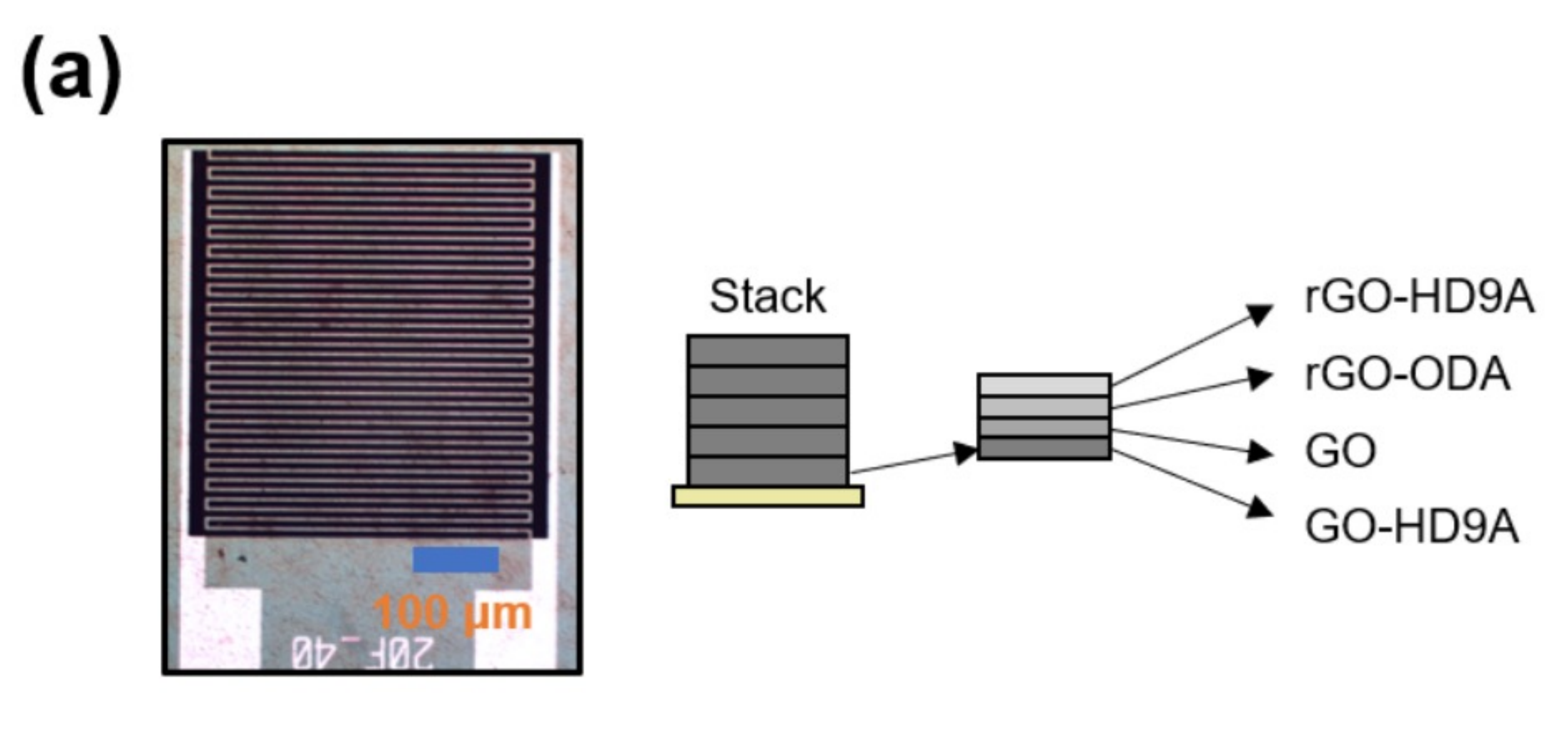


The curse of storing energy in a capacitor.

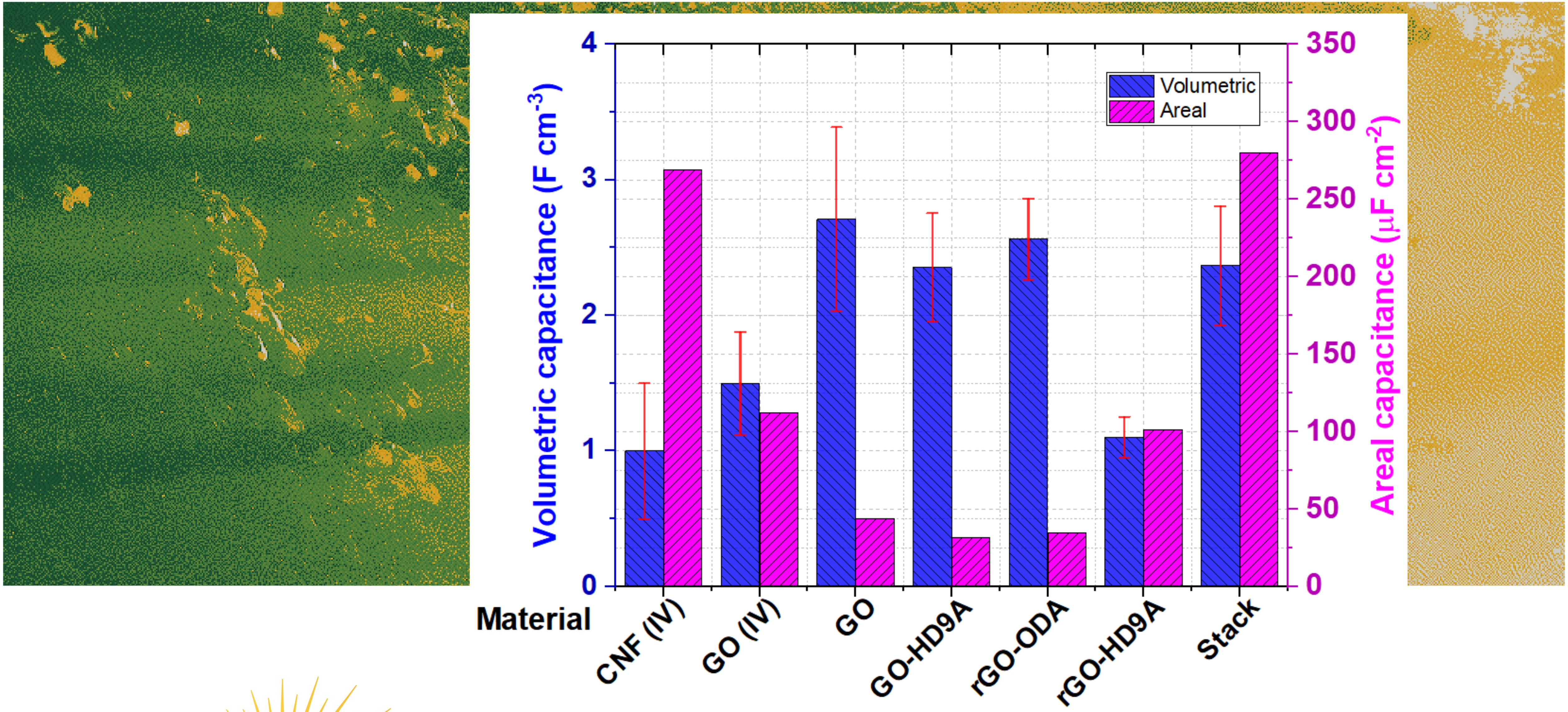
Charging at constant current means loosing…

$$\frac{E_R}{E_I} = \frac{R \cdot I \cdot C \cdot V}{R \cdot I \cdot C \cdot V + \frac{C \cdot V^2}{2}} = \frac{RI}{RI + \frac{V}{2}} \quad \rightarrow \quad I \ll \frac{V}{2R}$$





Agin Vyas et al., ”Spin-coated Heterogenous Stacked Electrodes for Performance Enhancement in CMOS compatible On-chip Micro-supercapacitors”, *ACS Applied Energy Materials* **2022** *5* (4), 4221-4231
DOI: 10.1021/acsaem.1c03745



GreEnergy Summer School 2022 - Cutting-edge electronics for eco-friendly energy

More information is available at **www.greenergy-project.eu**

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