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► **To cite this version:**

J Champavert, J Hurtaud, P Rannou, V Forge. Hydrovoltaic properties of self-assembled protein nanowires. MRS Fall conference - Symposium SB12-Conductive Biological Materials, Dec 2024, Boston, United States. hal-04829080

HAL Id: hal-04829080

<https://hal.science/hal-04829080v1>

Submitted on 10 Dec 2024

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Hydrovoltaic properties of self-assembled protein nanowires

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Recently, a new, versatile, and promising source of renewable energy from water has been proposed: hydrovoltaics [1-3]. This emerging technology allows for the direct generation of energy from the interaction between water vapor and functional nanomaterials. Due to the power output (a few tens of $\mu\text{W}/\text{cm}^2$), potential applications are primarily in low-consumption electronics, such as sensors and IoT devices. While hydrovoltaics is garnering significant attention, the underlying mechanisms remain a topic of debate [4].

In this study, we demonstrate the potential use of self-assembly protein, *i.e.* amyloid fibers, as hydrovoltaic biogenerator. These amyloid fibers are composed of protein nanowires, with a diameter of 10-20 nm and an average of several μm , which are non-pathological. The hydrovoltaic properties of these bionanowires have been observed in various forms: as a film or as a macro-wire. As macro-wires form, a potential difference forms naturally and spontaneously as it dries. Indeed, an open-circuit voltage (OCV) appears when humidity exceeds 40% relative humidity (RH). This OCV is directly correlated with humidity levels, increasing as humidity rises. For a single macroscopic wire, an OCV of 1.5 V was recorded at 85% RH. In the case of the film form, we demonstrated hydrovoltaic properties using protein films placed between two glassy carbon electrodes, leveraging a gradient of immobile charges. Electrochemical modifications are required on one of the electrodes (oxidation at the anode) to establish this gradient. Oxidation of water at the anode induces chemical changes in the protein side chains, leading to the appearance of an open circuit voltage (OCV) of around 0.4 V after a certain period and a power output of approximately $50 \mu\text{W}/\text{cm}^3$. In both cases, water adsorption on the materials' surface is crucial and determines the humidity level required to generate electricity.

Our work paves the way for further advancements in the "fusion" of desirable features, bringing the concept of a true biogenerator for electronics closer to reality.

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[2] L. Wang, W. Zhang, y Y. Deng, «Advances and Challenges for Hydrovoltaic Intelligence», *ACS Nano*, vol. 17, n.o 15, pp. 14229-14252, ago. 2023, doi: 10.1021/acsnano.3c02043.

[3] J. Xu et al., «Sustainable moisture energy», *Nat Rev Mater*, feb. 2024, doi: 10.1038/s41578-023-00643-0.

[4] X. Liu et al., «Power generation from ambient humidity using protein nanowires», *Nature*, vol. 578, n.o 7796, pp. 550-554, feb. 2020, doi: 10.1038/s41586-020-2010-9.