Millimeter scale electrochemical energy storage devices for paring with EH: a step towards enabling miniature autonomous wireless sensor networks

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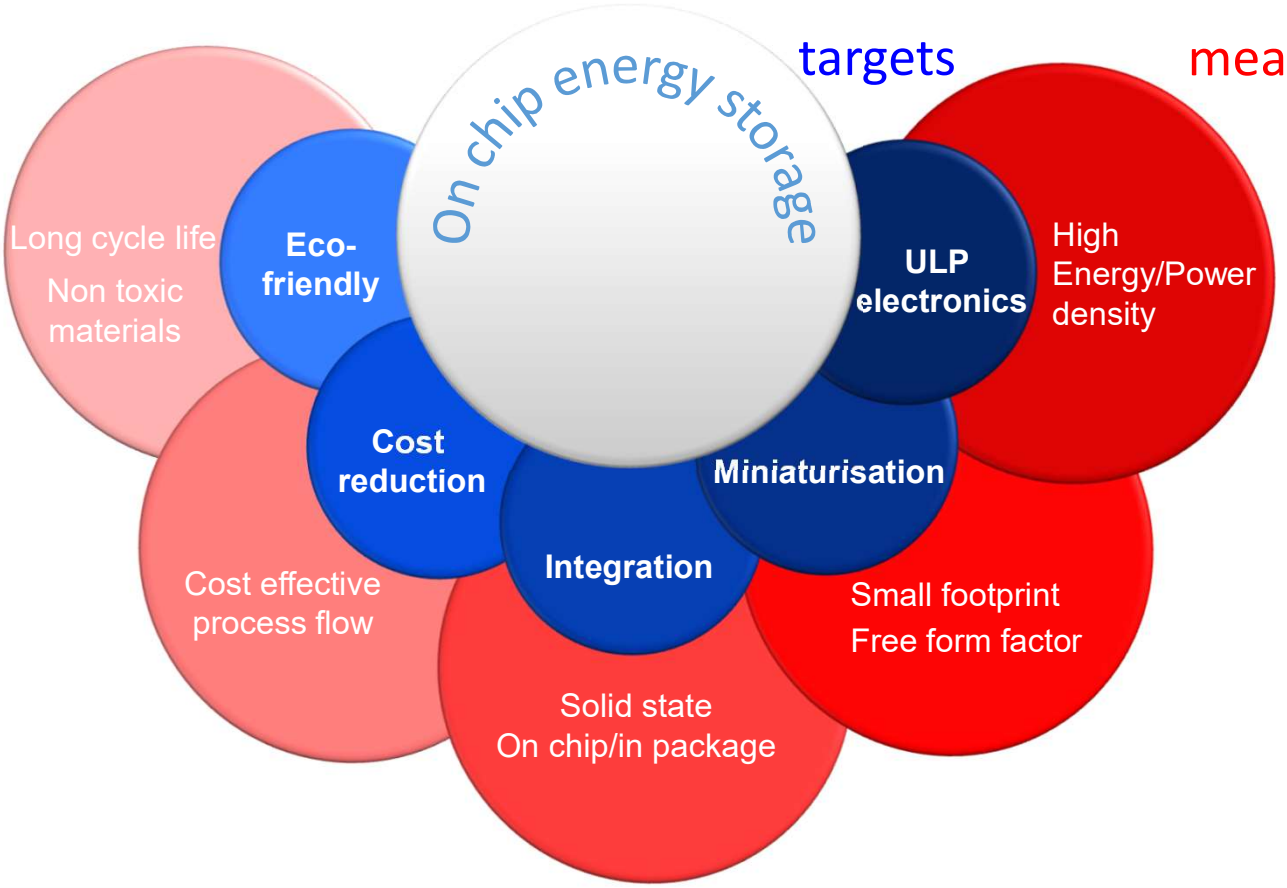
Outline

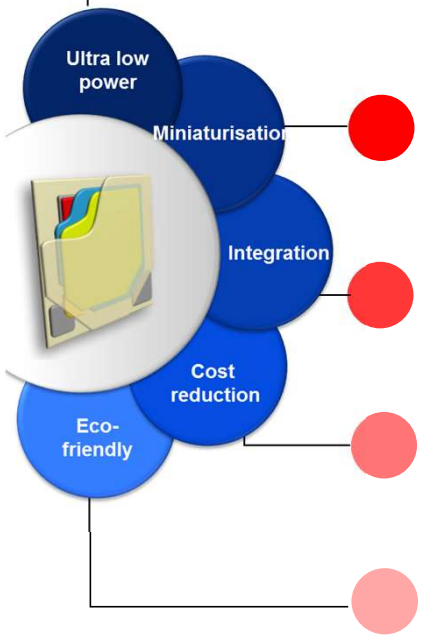
- Integrated energy storage devices, the main challenges
- Integrated ion capacitors: a paradigm shift
- Ion capacitors electrical performance
- Conclusion

Integrated energy storage : a key technology enabler



The emergence of novel multifunctional internet of things and wearable electronics = the development of innovative energy storage devices

Integrated energy storage : main challenges



≥10µF* (µAh)/mm²,** usually necessary for most demanding applications, thick (10µm+) active electrodes are needed

Advanced **patterning of exotic materials** (ionics) is mandatory

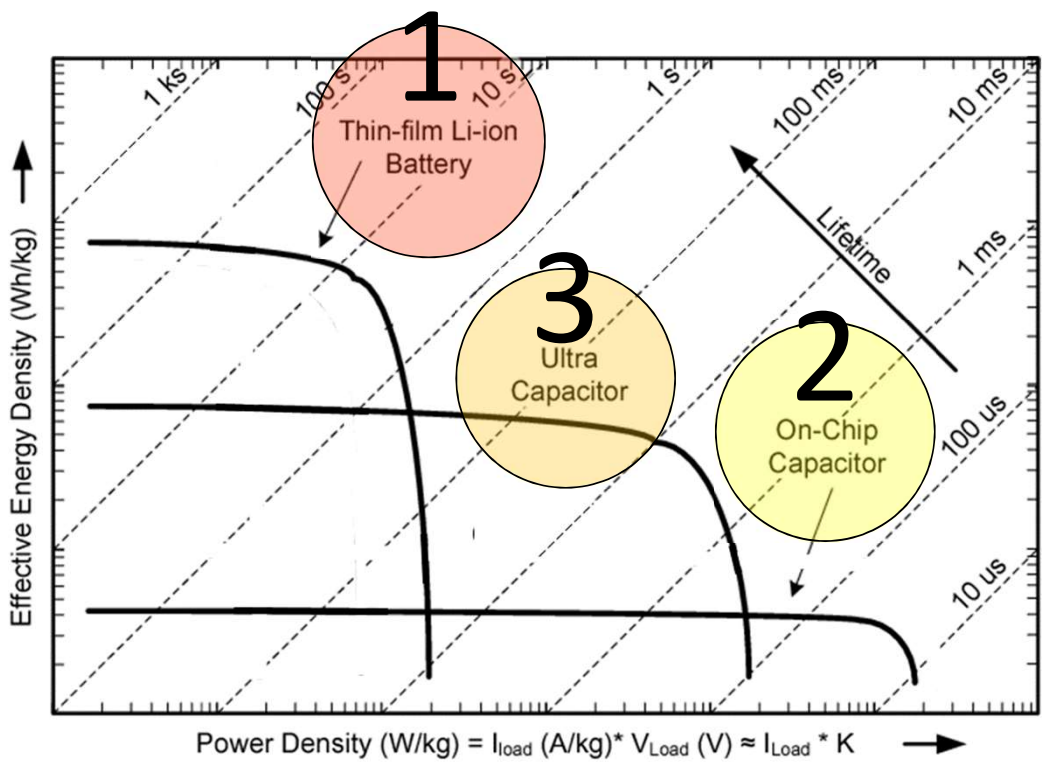
Compatibility with established **integration** approaches and packaging solutions are preferred

Especially for architectures with **thick electrodes and wafer level packaging**

Long cycle life (**1M*/1K**** full discharge cycles, **<10% capacity loss**)

* capacitors, ** batteries

Integrated energy storage, LETI developments

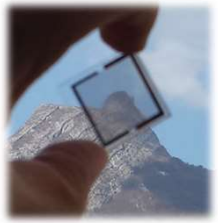


Thin film batteries at LETI

25x25 mm² TFB, 1mAh [1,2]

autonomous micro energy sources (AMES)

20x20 mm² TFB, 0.5mAh [4]



Smart windows
Transparent energy source

25x5 mm² TFB, 0.1mAh [5]

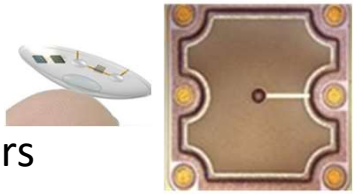
Nanodrone energy source (defense/civil)

5x5 mm² TFB, 5µAh [3]

System in package backup power

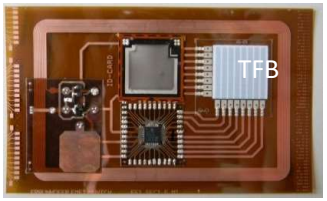
1-3 mm² TFB, >10µAh

Wearables
Implantable sensors



20x20 mm² TFB, 0.2mAh [6,7]

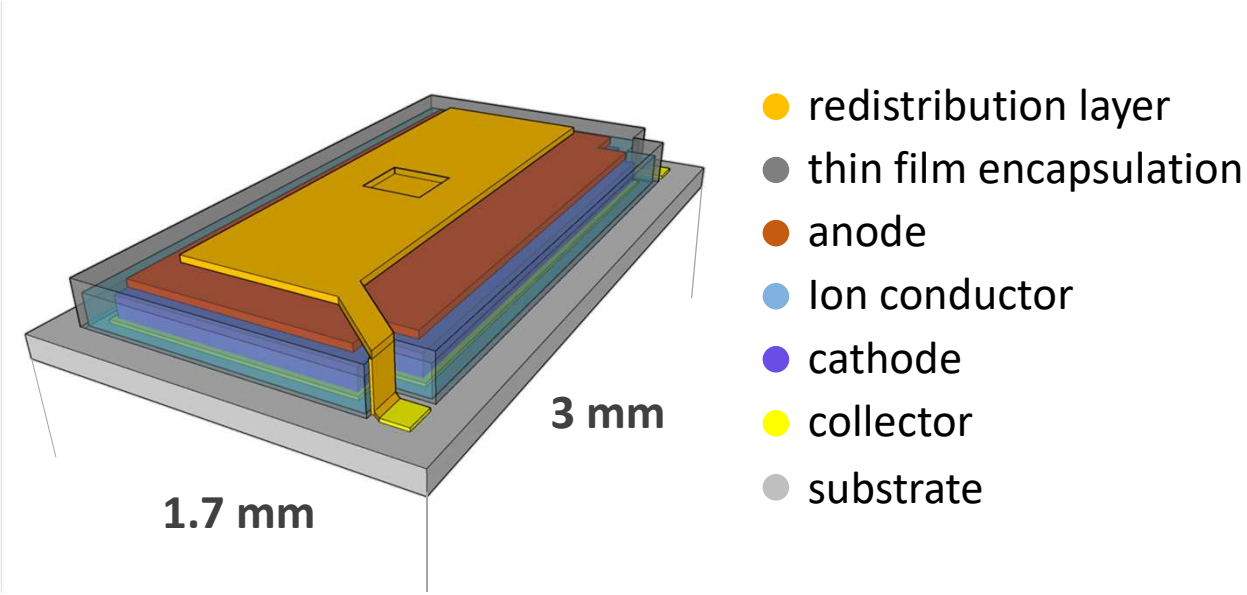
Flexible IoTs
System on foil



[1] ACS applied materials and interfaces 9(38), pp.33238-33249 (2017)
[2] Journal of Power Sources, 319, pp. 139-146 (2016)
[3] *Lithium Micro-Batteries, in Energy Autonomous Micro and Nano Systems (eds M. Belleville and C. Condemine), John Wiley & Sons, Inc., USA* (2012).
[4] ACS applied materials and interfaces 11(1), pp.683-690 (2019)
[5] PowerMEMS 2018 conference, in press
[6] J. Electrochem. Soc., Vol 164 (9), A1785-A1791 (2017)
[7] Electronic Components and Technology Conference (ECTC), IEEE 66th, 978-1-5090-1204-6/16 (2016)

Thin film batteries at LETI

TINY thin film batteries: schematic illustration

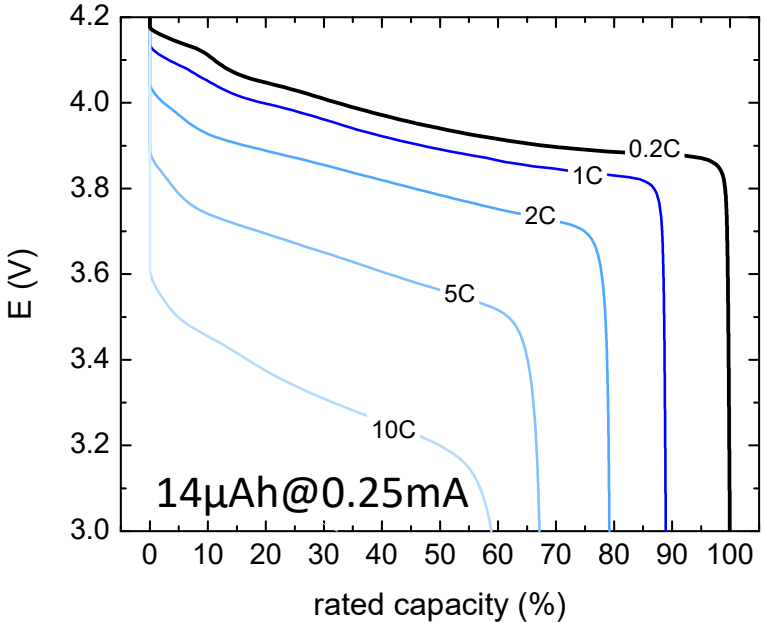


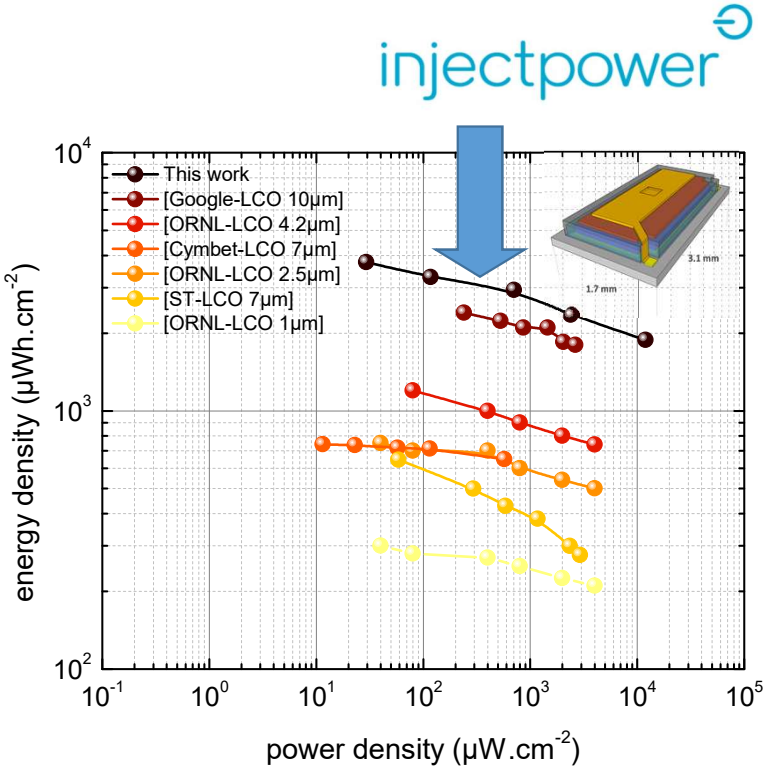
Device after dicing

-TINY platform for TFB : 8’’ fully compatible with microelectronics fabrication process
-free form factor, custom layout associated to advanced patterning capabilities

Thin film batteries

Capacity variation with current (0-0.25mA)





-TFBs exhibit the highest energy and power densities, reaching **0.89 mAh.cm^{-2} at 10µA.cm^{-2} and 0.45 mAh.cm^{-2} at 3mA.cm^{-2}** in comparison to results from literature

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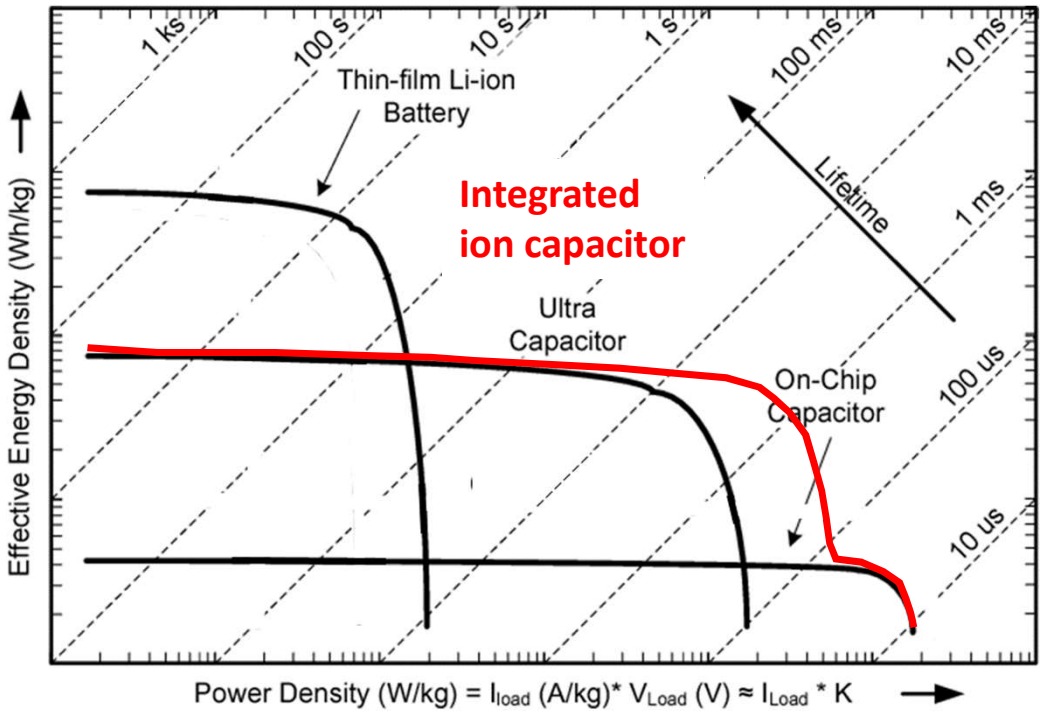
Integrated ion capacitors: a paradigm shift

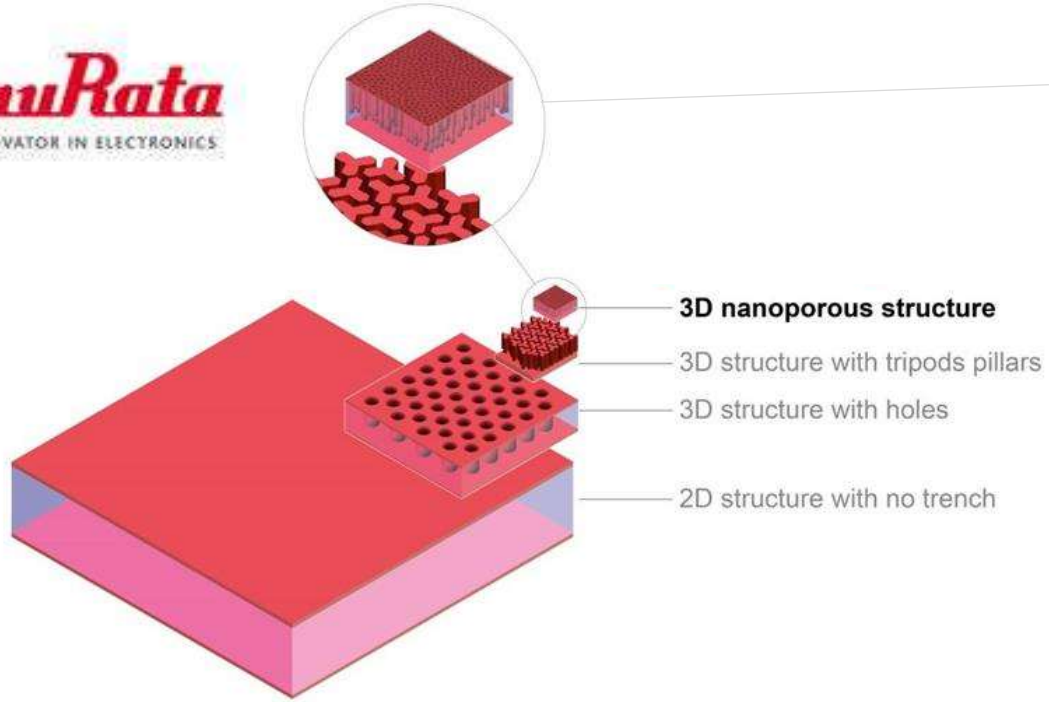
100µF/mm²

1µF/mm²



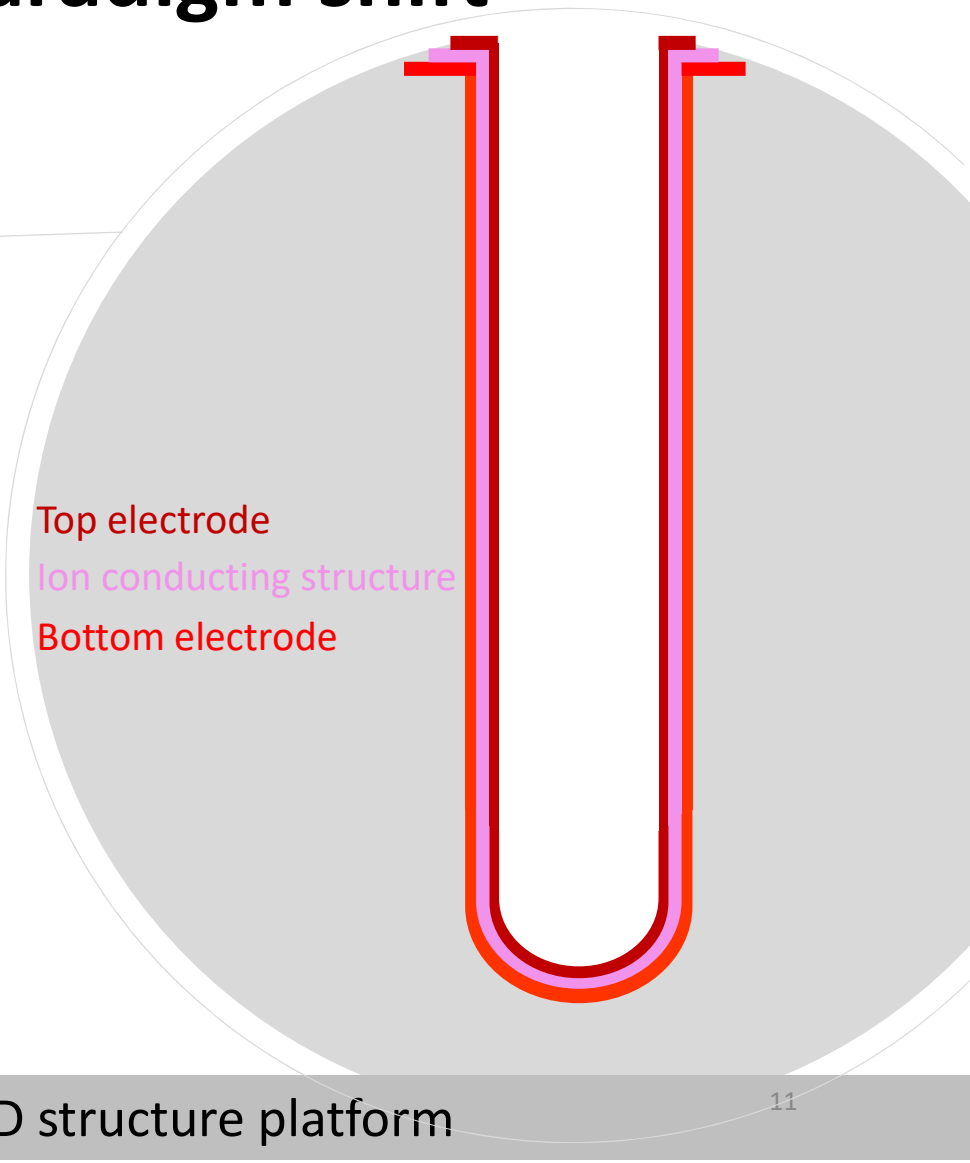
-a broadband all-in-one capacitor encompassing ion and dielectric storage mechanisms
-ion storage maintained at high power density (/frequencies)
-on chip integration

Integrated ion capacitors: a paradigm shift



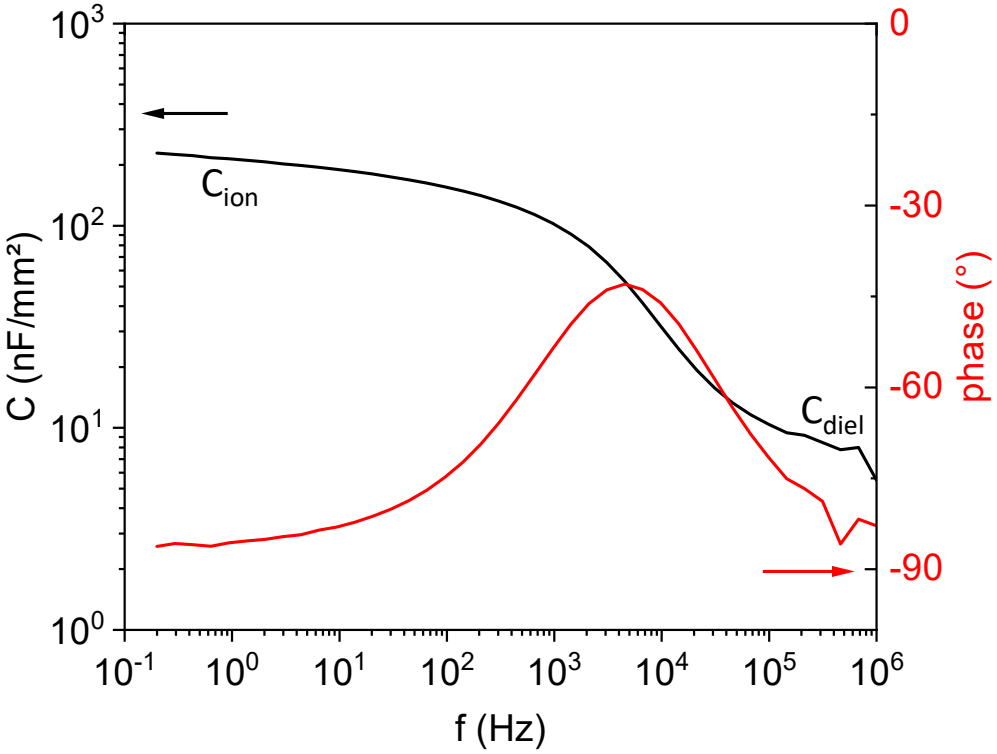
[40µm silicon capacitor for in-package power networks]
Murata has launched a range of high capacity silicon capacitors aimed at power distribution networks (PDN) in chip packages for mobile and high-performance computing (HPC) applications.

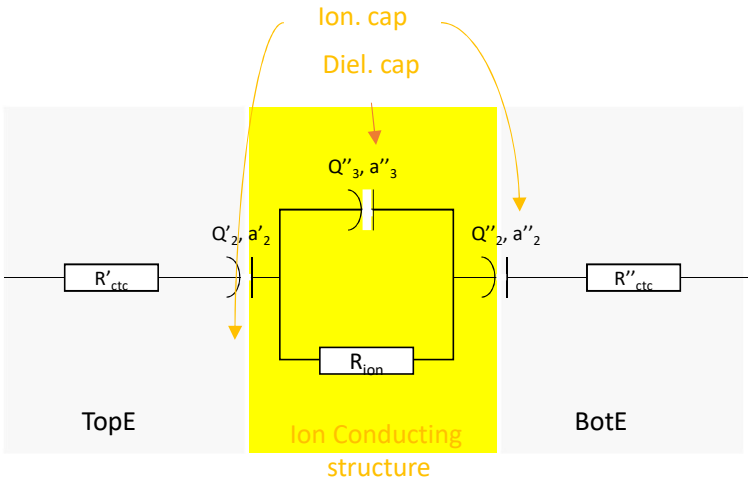
https://www.murata.com/en-eu/news/capacitor/siliconcapacitors/2021/0618



-integration of an ion conducting based structure in a 3D structure platform

Integrated ion capacitors: a paradigm shift





-C_{ion} related to electrical double layer formation at the ion conducting electrode interfaces
-C_{diel} related to polarization of the solid state ion conducting structure

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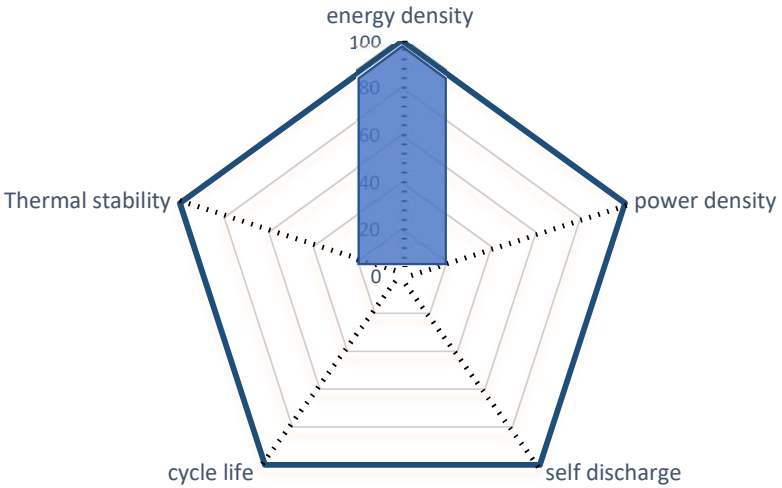
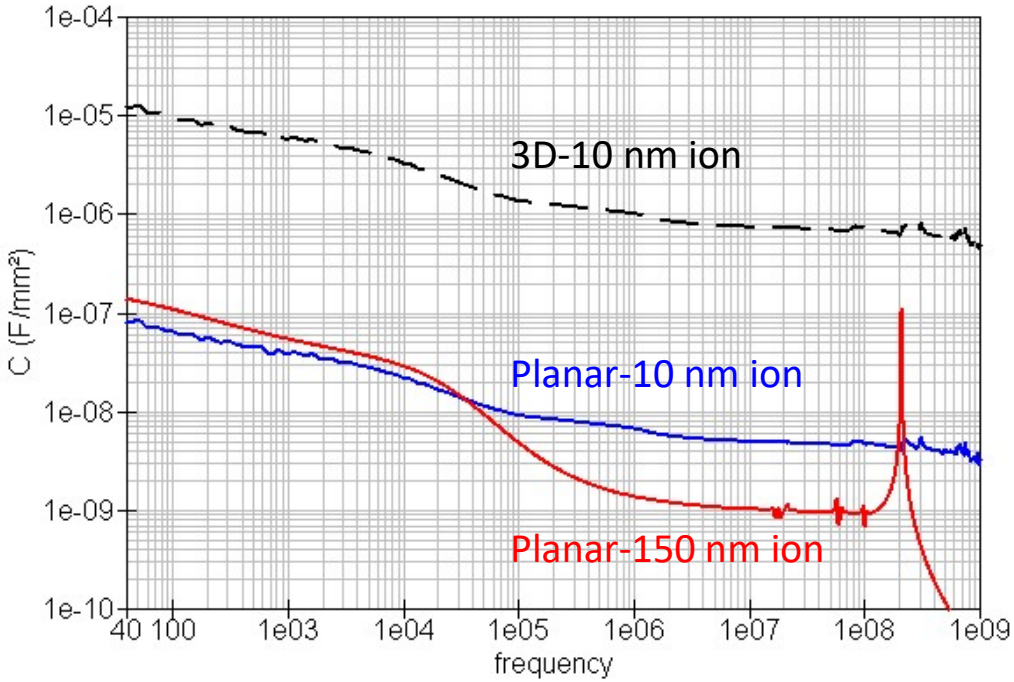
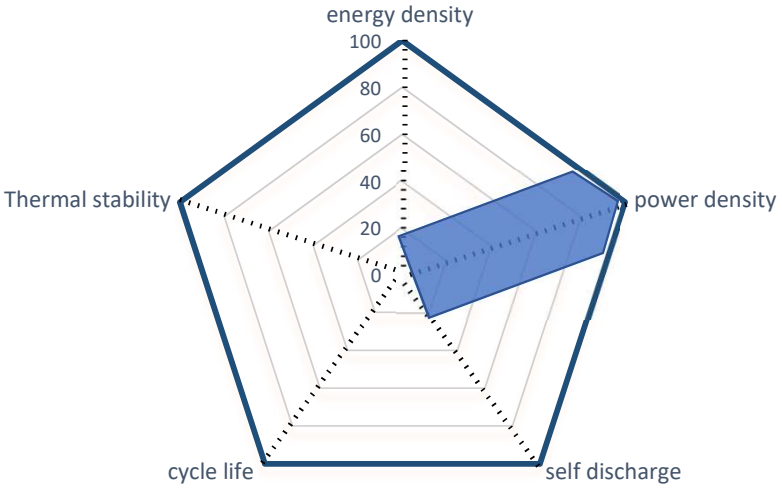
Ion capacitors electrical performance

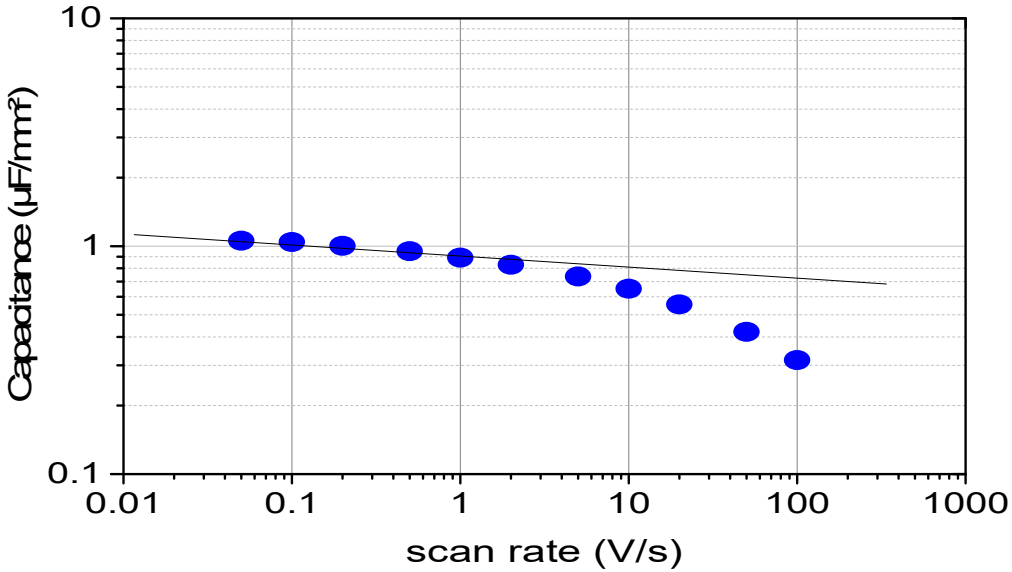




-10µF/mm² ion capacitance for Gen1 device architecture and materials

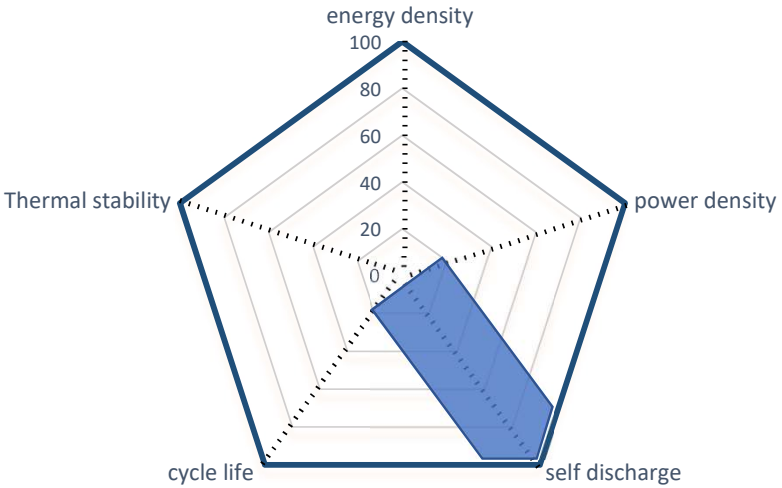
Ion capacitors electrical performance

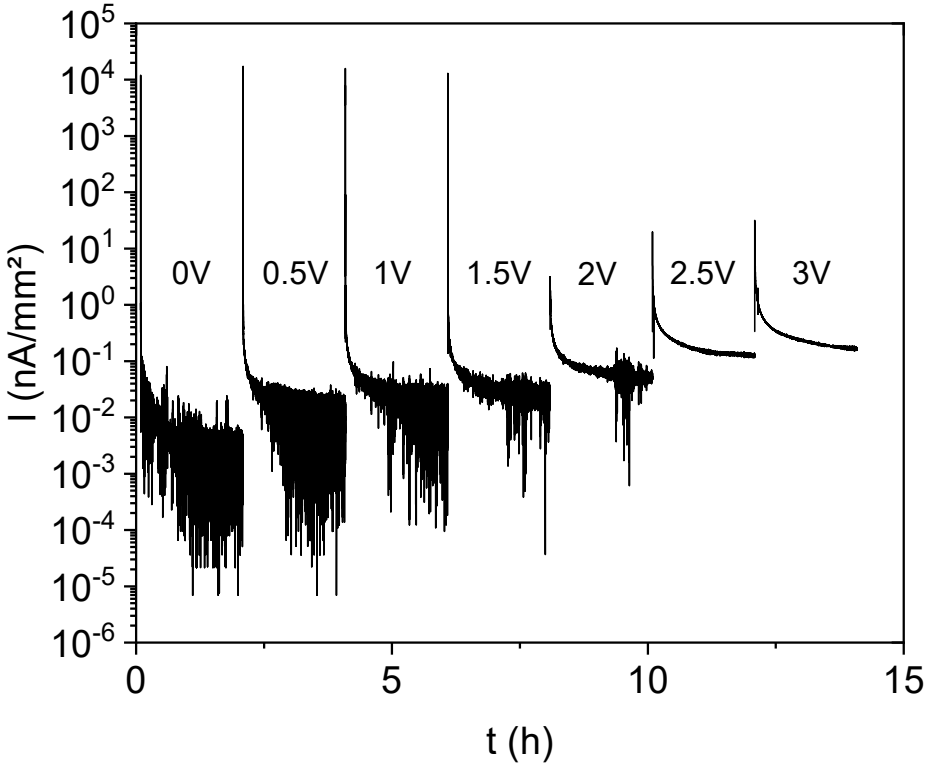




- 10% loss in capacitance from 50 mV/s to 1 V/s (electrodes limitation)
-capacitance fading for higher scan rates (ion conducting limitation)

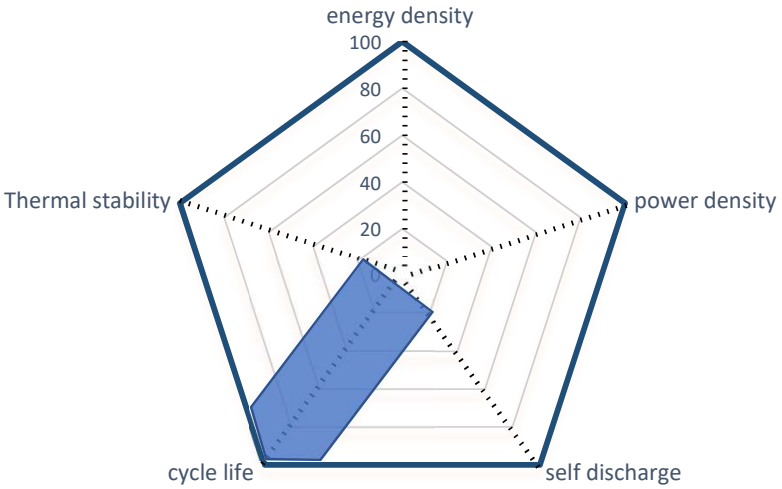
Ion capacitors electrical performance

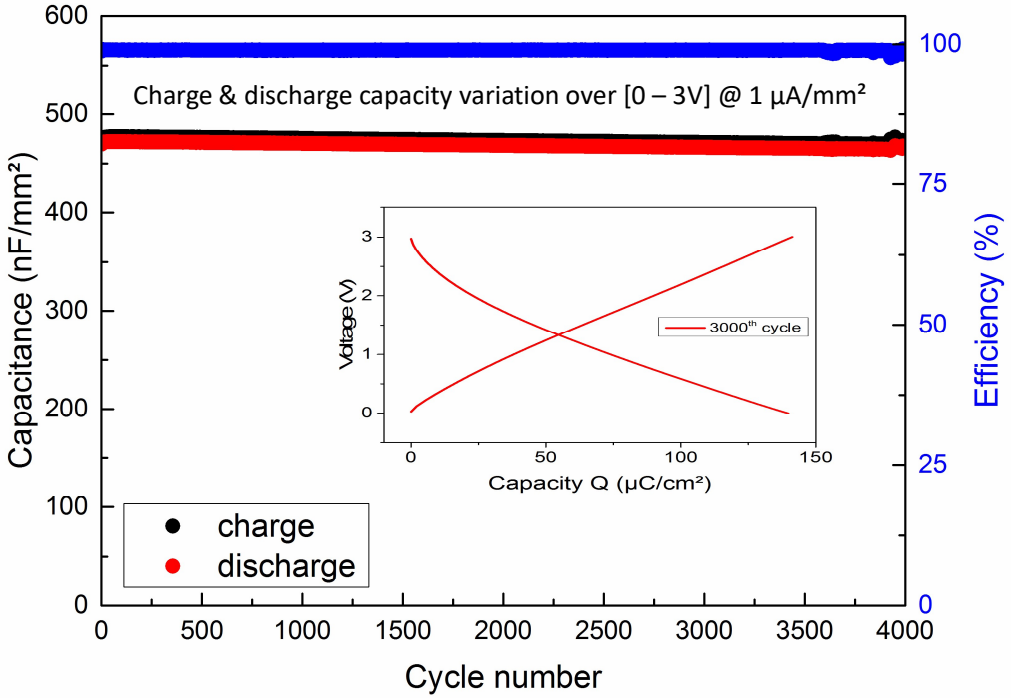




- Sub nA/mm² self discharge current density up to 3V potential

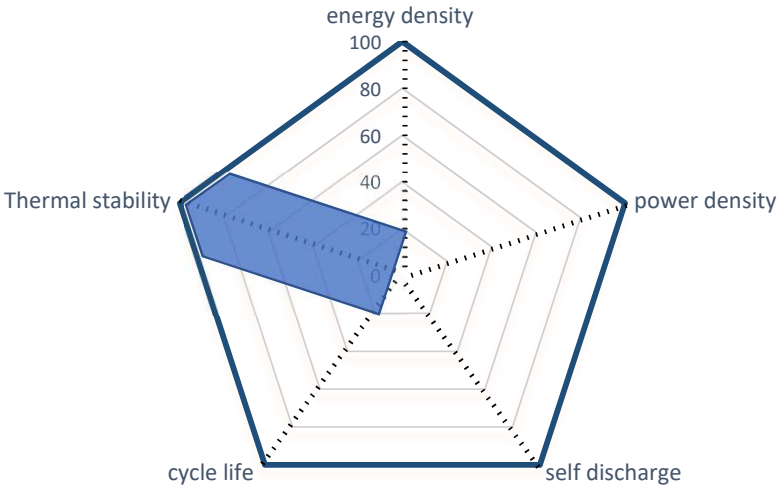
Ion capacitors electrical performance

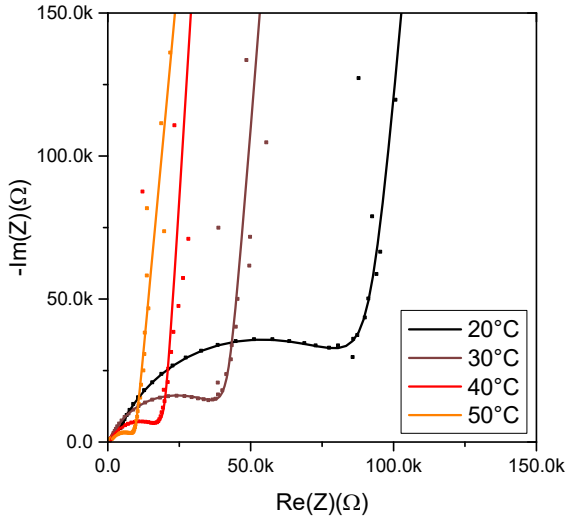


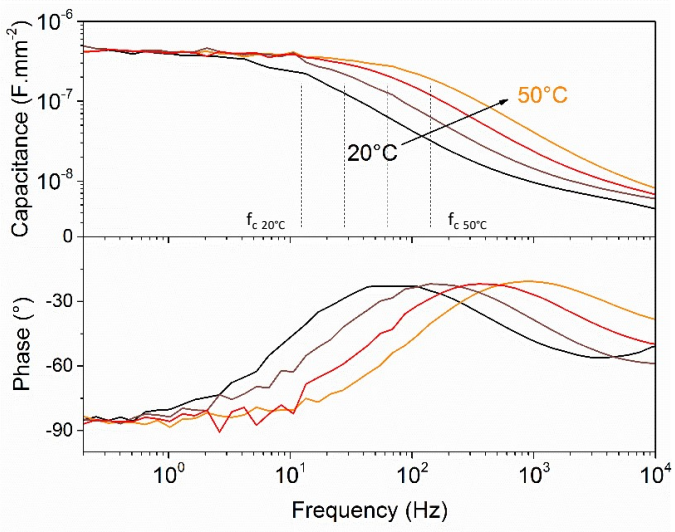


- High cycling behavior with 99,8% coulombic efficiency, almost perfectly reversible cycles
- Capacity decay of 5.10^{-4} %/cycle

Ion capacitors electrical performance







- Arrhenius' law respected within T range
- Switch between ion conduction and dielectric modes shifted towards higher frequencies, no change in capacitance values

Conclusion

- An innovative integrated ion capacitor has been proposed and successfully fabricated to demonstrate a broadband behavior from DC to GHz

- The device encompasses concomitantly electrical double layer and dielectric capacitance, respectively of 10 and 1 µF/mm² below/above 10KHz. Future generation will focus on a switching frequency around 1MHz and a 100µF/mm² for DC range capacitance

- Standard microfabrication process flow (8’’) has been used and should allow for a compatibility with an on chip integration approach

➔ ion integrated capacitor should be of interest for a wide scope of applications, especially in the field of nanoenergy storage and processing

Acknowledgements

Warm thanks to our partner MURATA and INJECTPOWER for the fruitful collaboration.

- **Related Publications**

[1] S. Oukassi et al., IEEE International Electron Devices Meeting (IEDM), 2019, doi: 10.1109/IEDM19573.2019.8993483.
[2] V. Sallaz et al., ECS Meet. Abstr. 2019, doi: 10.1149/ma2019-02/3/161.
[3] V. Sallaz et al., J. Power Sources 2020, doi: 10.1016/j.jpowsour.2020.227786.

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