

# Biodegradable Nonvolatile Memory Composed of Almost Nanocellulose

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Discarding the electronic instruments is a serious social issue, since the materials used in electronic devices are not biodegradable, not renewable and sometimes toxic to the environment and the living beings. One idea to overcome this issue is the development of electronic devices composed of biodegradable, renewable, environmentally safe materials, however, in general such materials are mechanically and thermally fragile and therefore it has been difficult to realize the robust electronic properties. In this study, we demonstrate the biodegradable nonvolatile memory composed of almost nanocellulose. Nanocellulose is most abundant biomass on earth and its excellent mechanical and thermal stability has been recently reported. The device consists of nanocellulose substrate, nanocellulose film memory [1] and electrodes, and is 99.3 vol.% composed of nanocellulose. The device showed the robust memory properties and the good scalability down to single nanocellulose scale ( $\sim 15\text{nm}$ ). At the end of use, the electrode materials could be separated in water by simply applying the sonication. Furthermore, the device was fully biodegradable within 30 days in the natural soil. Thus, our findings open the platform for environmental friendly green electronics using biodegradable nanocellulose.

[1] K. Nagashima et al. *Sci. Rep.* **4**, 5532 (2014)

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## Background

Consumer electronics have greatly contributed the economic growth and improved the human life in past decades. However, now discarding the electronic instruments is a serious social issue, since the materials used in electronic devices are not biodegradable, not renewable and sometimes toxic to the environment and the living beings.

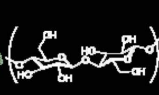


3.2 million tons of electronic waste per year in US

What is an alternative way for sustainable electronics?

## Paper electronics ~toward sustainable electronics~

**Key technology** : Cellulose nanofiber paper (CNP)

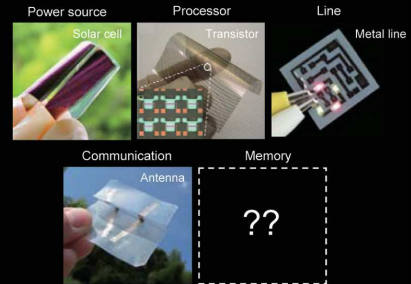


- Renewable
- Recyclable
- Biodegradable

Cellulose nanofiber paper (d=15nm)



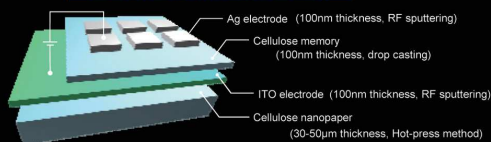
**Electronic device elements on CNP**



Can we demonstrate the eco-cycle compatible nonvolatile memory device?

## Experimental

**Nanocellulose based Paper Memory**



-Characterization-

- UV-visible spectrometer
- Atomic force microscopy (tapping mode & contact mode)
- Semiconductor parameter analyzer (Keithley4200SCS, air, room temperature)
- Ag: +/-, ITO: GND, current compliance 50μA-1mA

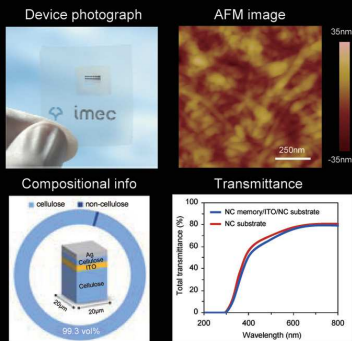
-Biodegradation experiment-



Natural soil 4L sampling in September at 34:49:30 north latitude 135:31:28 east longitude Temperature 22±2°C Humidity 92±3% Plastic bag

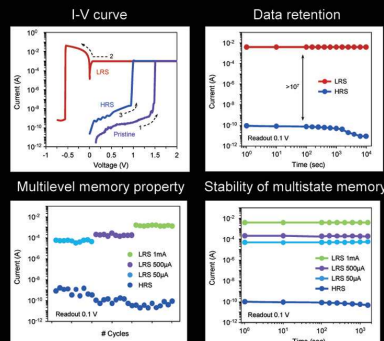
## Results and Discussions

**Structural characteristics**



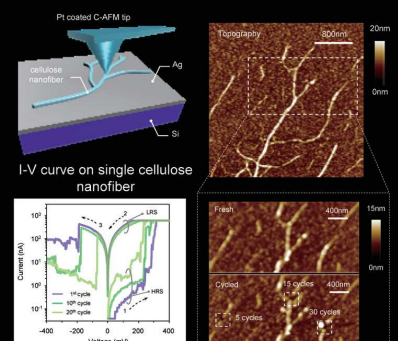
99.3% volume fraction of cellulose in paper memory

**Performance of Nonvolatile Memory**



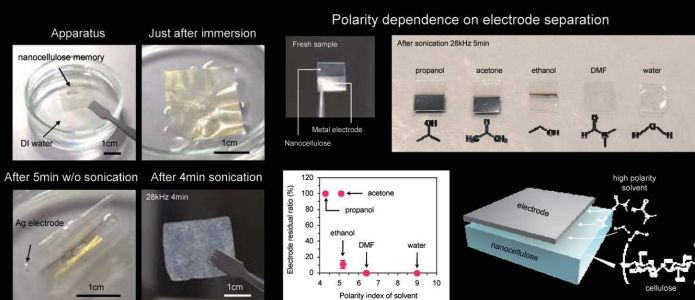
Clear nonvolatile memory property in paper memory

**Potential scalability of paper memory**



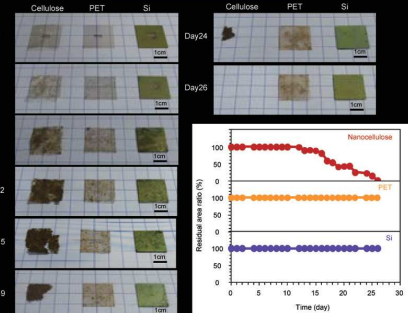
Paper memory works down to a single cellulose nanofiber scale

**Material sorting for recycle**



Electrodes can be sorted by simply applying the sonication in polar solution

**Biodegradability**



Paper memory showed high biodegradability into natural soil

## Summary

- Paper memory with 99.3 % volume fraction of cellulose was demonstrated for the first time.
- Paper memory is recyclable with low energy process and biodegradable into natural soil.

References [1] Nagashima et al. *Sci. Rep.* 4, 5532 (2014) [2] Celano et al *in preparation*