Three-dimensional network topology for in-materio reservoir computing

Saman Azhari[1,2,*], Deep Banerjee[1,2] Yuki Usami[1,2], Hirofumi Tanaka[1,2,*]

LSSE, Kyushu Institute of Technology [1], Neuromorph Center, Kyushu Institute of Technology [2]

E-mail: {saman, tanaka}@brain.kyutech.ac.jp

[Introduction] The limitations of semiconductor industry prevent us to fully utilize artificial intelligence (AI) capacity. The inability to utilize AI to its full capacity arises from the lack of parallel memory and processing potential in current computational devices. These limitations have led us towards alternative computational devices. One of the growing fields of unconventional computing known as reservoir computing, employs the dynamical properties of the network to process information. Therefore, currently different research groups are investigating various properties of materials, to construct a functional in-materio reservoir device (I-mRC).

Although there has been great findings and reports on such materials and devices[1–4)], the influence of network structure and topology of such physical devices remains unknown. Since the root of the dynamical behavior observed in these devices is the physical properties of their constituent materials; it is also possible that the network structure and device topology may influence the dynamics of the device. Herein we report the fabrication of two- and three-dimensional (2D and 3D respectively) network of single walled carbon nanotubes (SWNT)-polyoxometalate (POM) complex and compare their reservoir computing performance. We believe that the 3D topology of the device results in increased number of junctions that improves the reservoir performance.

[Methodology] To fabricate the devices 1 mg of SWNT (Merck) was dispersed in 10 mL of isopropyl alcohol (IPA) via sonication for 1 hour. Next 10 mg of phosphomolybdic acid hydrate (POM) was dissolved in 2 mL of acetonitrile and added to SWNT dispersion. The mixture was then sonicated for 4 hours at 18 °C. To fabricate the 2D device 1 mL of the dispersion was filtered via vacuum filtration and placed on the electrodes, the filter paper was then removed using acetone vapor. The 3D device was fabricated via hard template technique in which melamine sponge was immersed in the dispersion and sonicated for 5 minutes before drying in the oven at 70 °C.

[Results] The FESEM images indicate that the 2D network on SWNT-POM is exhibit nearly uniform distribution throughout the substrate with stacking and cross connections while the distribution in the 3D sample follows the melamine sponge skeleton and exhibit similar tendencies to the 2D network distribution. The I-V characterization of the devices suggest that the 3D network exhibit stronger nonlinear tendencies which is ideal for reservoir computing devices. Finally, the 3D device exhibit superior waveform generation benchmark task indicating the importance of network topology on the performance of I-mRC devices.

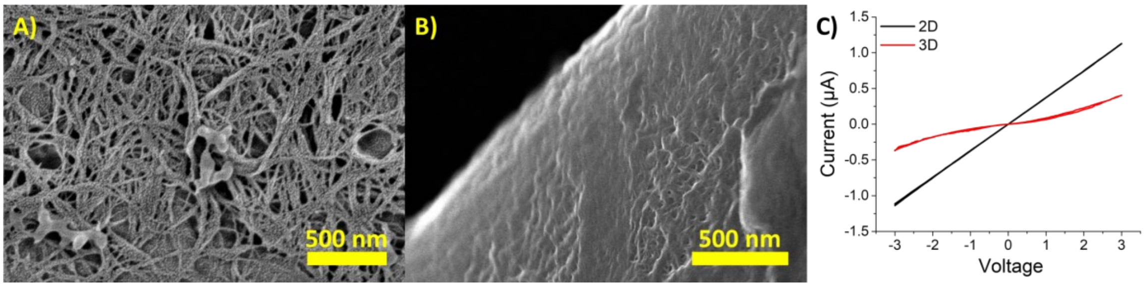

Figure 1. A & B) FESEM images of 2D & 3D SWNT-POM network, respectively; C) I-V characteristics of 2D and 3D device

References

1) Hadiyawarman, Y. Usami, T. Kotooka, S. Azhari, M. Eguchi, H. Tanaka, Jpn. J. Appl. Phys. **60**, (2021).
2) Usami, Y., Ven, B., Mathew, D. G., Chen, T., Kotooka, T., Kawashima, Y., Tanaka, Y., Otsuka, Y., Ohoyama, H., Tamukoh, H., Tanaka, H., Wiel, W. G. & Matsumoto, T. Adv. Mater. 2102688 (2021).
3) Banerjee, D., Azhari, S., Usami, Y. & Tanaka, H. Appl. Phys. Express **14**, 105003 (2021).
4) Banerjee, D., Kotooka, T., Azhari, S., Usami, Y., Ogawa, T., Gimzewski, J. K., Tamukoh, H. & Tanaka, H. Adv. Intell. Syst. **4**. 2100145 (2022).