Electrical memorability in silver nanoparticle composite operated at the conductor-to-insulator percolation threshold

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Abstract -The conductor-to-insulator (CtI) phase transition in silver-nanoparticle composites' static material and electrical properties has been explored for years, except for its potential for further applications based on dynamics, i.e., time-varying properties running. Traditional applied percolation theory suggested no hint of memorability demonstrated in our work. Then, our research examines the dynamic electrical behavior of silver-nanoparticle composites (SNPC), focusing on resistance change with time subjected to external pulses. As indicated by experimental results, an avalanche operating at SNPC's percolation CtI threshold resembled an enforcement process. The integrated time versus SNPC samples' critical exponent was also identified as an effective parameter for characterizing intrinsic properties. A thermal-based recovery treatment was then applied to erase stored information, showing that written and rewritten samples retained similar critical exponents. Encoding and decoding two four-alphabet strings into an SNPC sample have been demonstrated before and after thermal recovery. These insights support ongoing research into optimizing SNPCs' material properties and operational parameters for enhanced performance in such applications.

I. Introduction

Composite materials, known for their tunable dielectric constants and magnetic permeability, have gained significant attention across various fields. Percolation theory has been widely applied to describe phenomena near critical transitions, such as the sharp change in electrical conductivity of silver-nanoparticle composites (SNPCs) when the nanoparticle volume fraction exceeds a critical threshold. However, near this critical point, the application of voltage pulses induces a significant resistance drop—dynamic behavior unexplained by traditional percolation theory.

To address this limitation, we propose replacing the conventional resistor network model with a memristor network, hypothesizing that SNPCs exhibit memory-like behavior under external electrical stimuli.

This study evaluates SNPCs' memory potential through a series of experiments designed to: (1) identify the percolation threshold of silver nanoparticle volume fractions, (2) confirm abrupt resistance drops under electrical stimuli, and (3) demonstrate reversible resistance changes via thermal treatment. These findings aim to establish SNPCs as viable candidates for memory applications in electronic circuit design.

II. Method

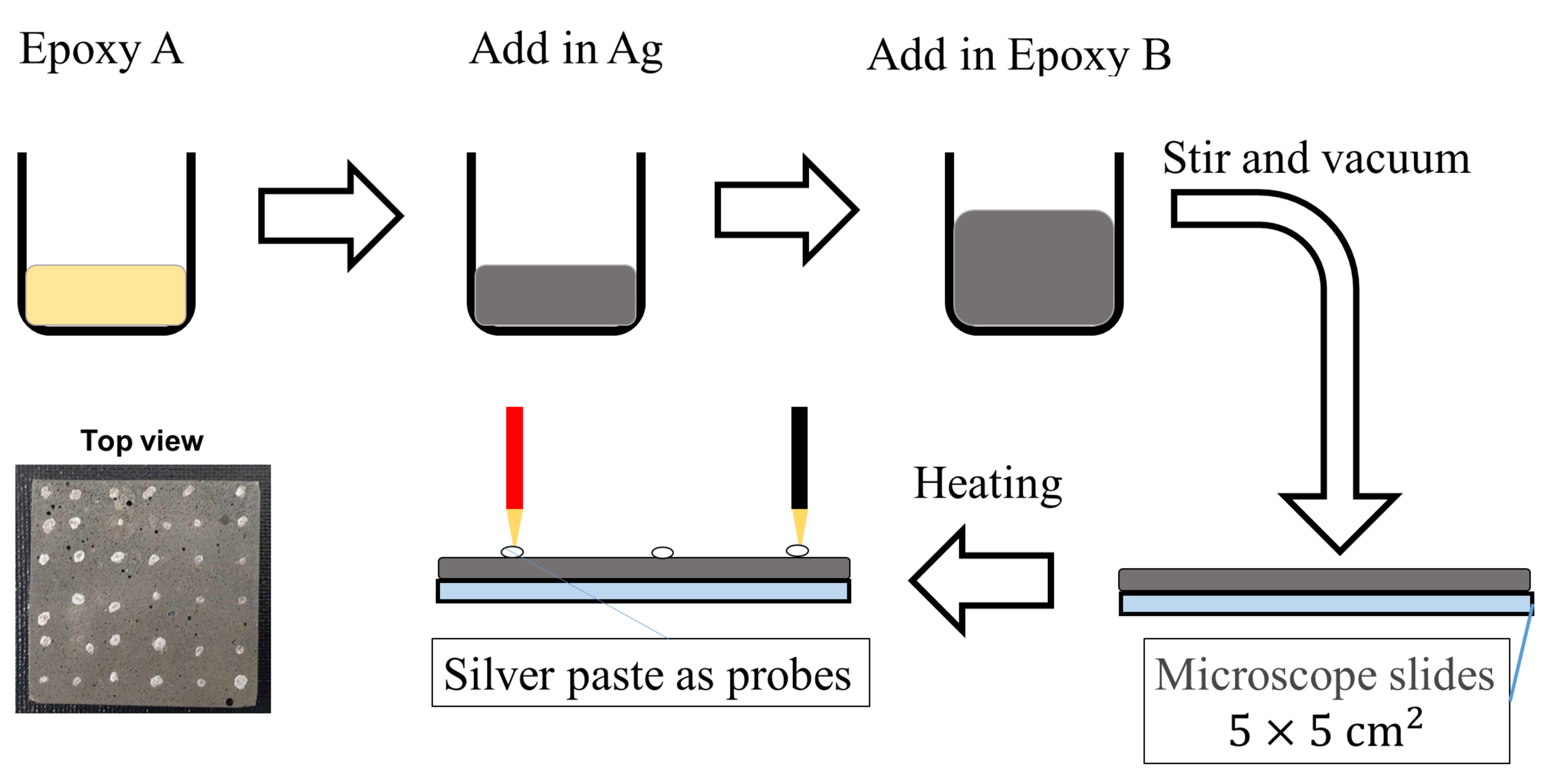

Fig. 1. Making these samples follow the steps: (1) Pour 1–3 g of **Epoxy-A** into the beaker, record its weight $\boldsymbol{W_A}$. (2) Add the corresponding amount of **silver powder** into the beaker based on the desired concentration, record its weight $\boldsymbol{W_{Ag}}$. (3) Measure approximately **1/3 of** $\boldsymbol{W_A}$ **for Epoxy-B** (A:B=3:1), pour it into the beaker, and record its weight $\boldsymbol{W_B}$. (4) Use a stirring rod to mix the components thoroughly until all the powder is evenly blended with the epoxy. (5) After mixing, shape the mixture into the desired sample form.

Final Volume Fraction Formula:**vol%** $= \dfrac{\frac{W_{Ag}}{10.49}}{\frac{W_{Ag}}{10.49}+\frac{W_A+W_B}{1.13}}$

III.Result and discussion

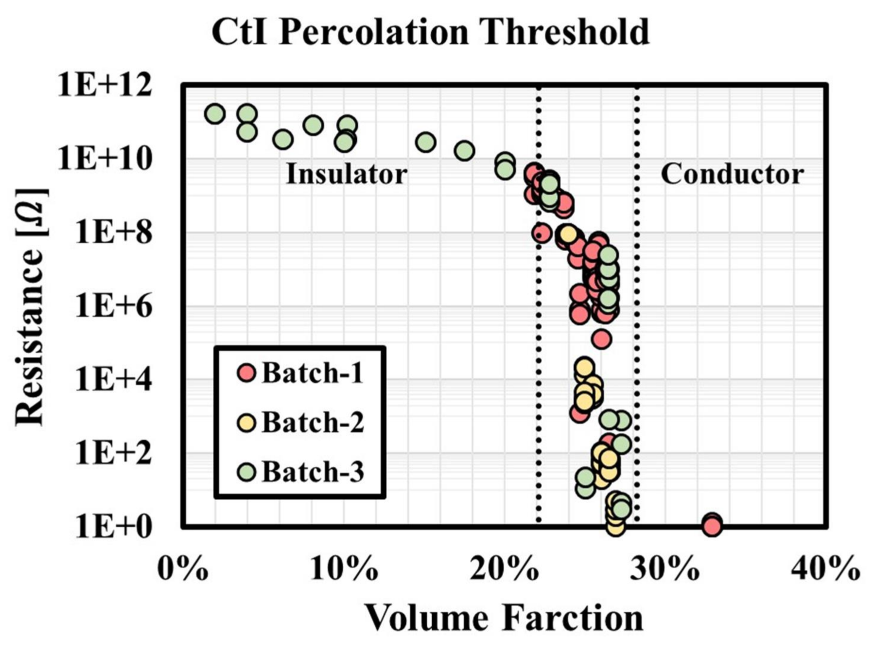

Fig. 2. Experiment data of SNPC CtI Phase Diagram. The CtI phase transition point is about vol. fraction = 0.25.

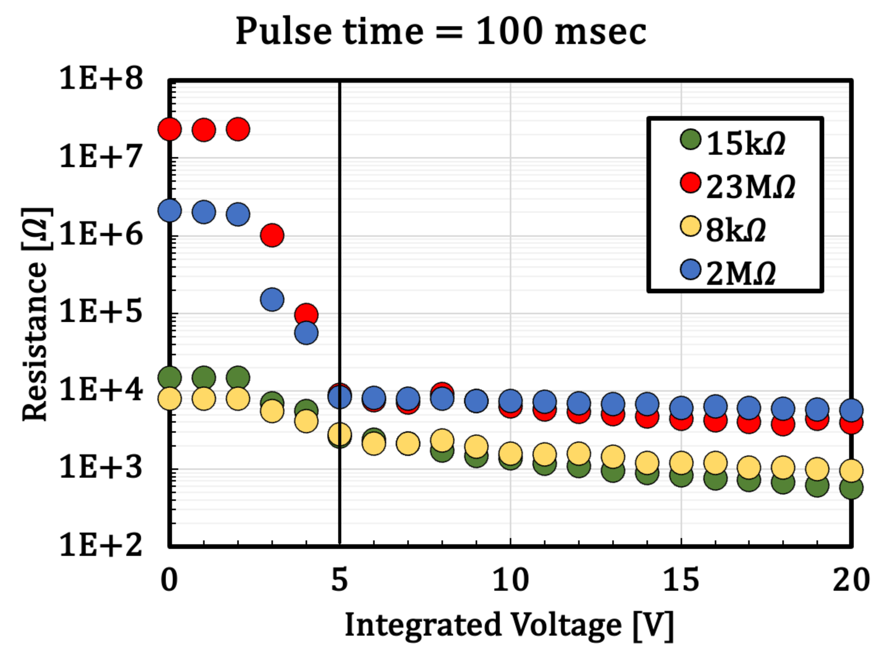

Fig. 3. The working pulse selection. According to actual situation, 12V was selected to be the forming pulse.

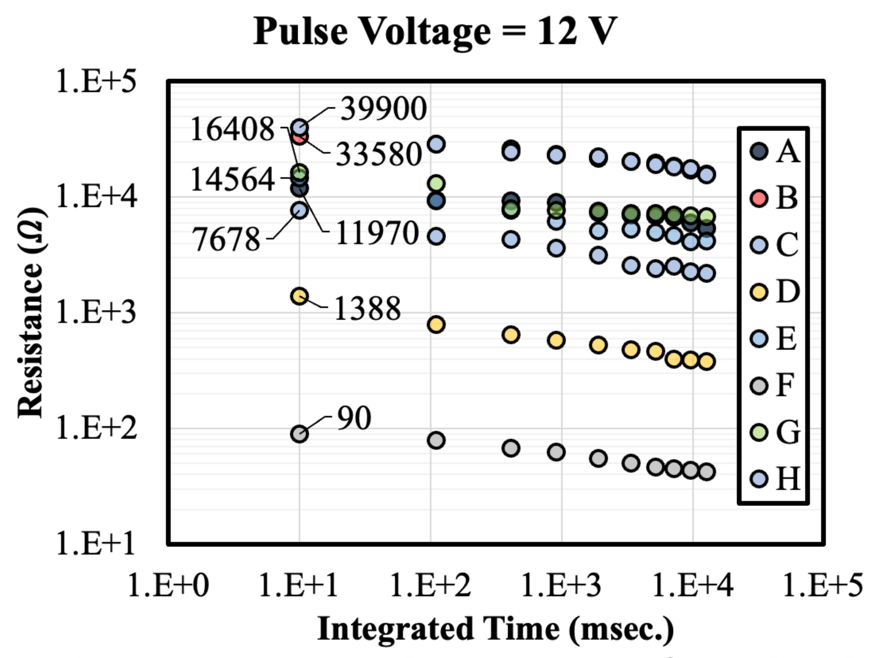

Fig. 4. Dynamical response of randomly selected eight samples. Straight lines in the log(R)-log (integrated time) plane imply critical behavior. The slope of all eight samples was similar, but the R_{ini} varies, which is consistent with Fig. 1.

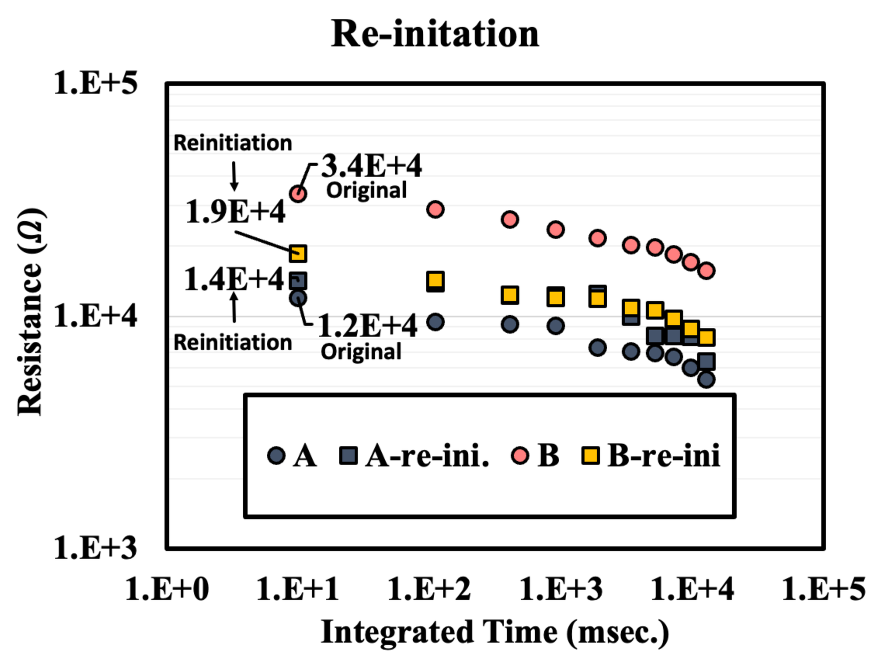

Fig. 5. Re-initiation assigns a new resistance, R_{re-ini} of two probed points (Low R_{ini} is not presented). Yet the $R_{re-ini} \neq R_{ini}$, the same linearity in the log-log plot emerges.

IV.Application

We developed a data storage method using SNPC by encoding paths between points in a grid. For N^2 points, path-based encoding allows for $2^{2N(N-1)}$ configurations, significantly surpassing binary storage capacity. Resistance measurements determine connectivity, with resistances below 100kΩ indicating connected paths.

Using a 3×3 grid, signals applied to specific regions did not affect others. Initial resistance was 10MΩ, and encoded data ("NTHU") was successfully stored(upper red and blue square), erased by heating, and re-encoded "COSR", demonstrating reusability and high storage potential.

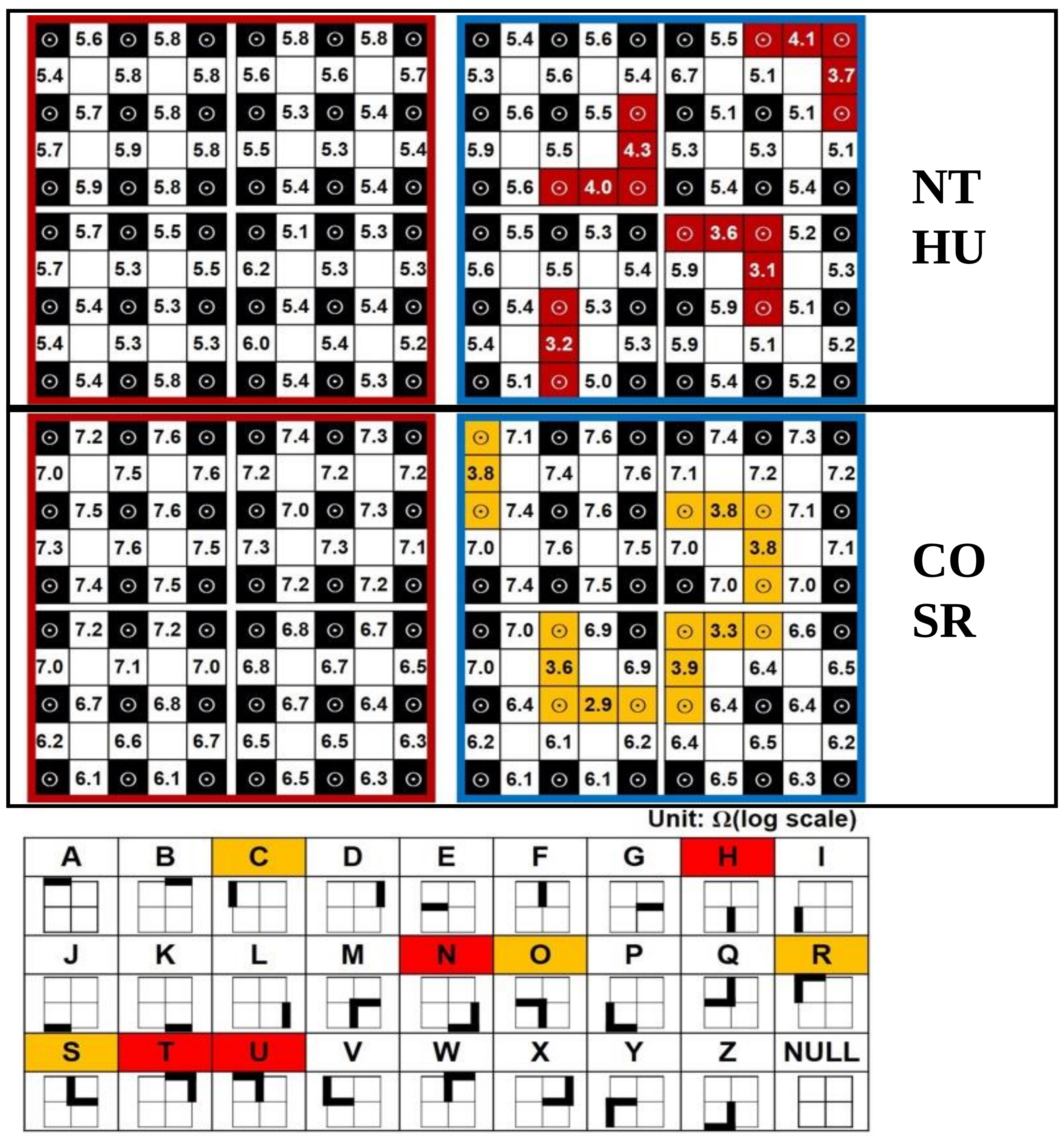

Fig. 6. Demonstration of patterns writing on an SNPC sample. The symbol ⊙ stands for an electrode. The resistance is presented in a log scale. Resistance drops occur due to external voltage pulse stimulation. The pattern is selected using an alphabet coding table.

V. References

[1] L. Qi, B. I. Lee, S. Chen, W. D. Samuels, and G. J. Exarhos, "High-Dielectric-Constant Silver–Epoxy Composites as Embedded Dielectrics," *Advanced Materials*, vol. 17, no. 14, pp. 1777-1781, 2005, doi:https://doi.org/10.1002/adma.200401816.

[2] S.-C. Su and T.-H. Chang, "Manipulating the permittivities and permeabilities of epoxy/silver nanocomposites over a wide bandwidth," *Applied Physics Letters*, vol. 116, no. 20, p. 202904, 2020, doi: 10.1063/5.0006835.

[3] S. Kirkpatrick, "Percolation and Conduction," *Reviews of Modern Physics*, vol. 45, no. 4, pp. 574-588, 10/01/ 1973, doi: 10.1103/RevModPhys.45.574.