An Inkjet-Printed Memristor Device for Neuromorphic Computing: Fabrication and Characterization

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Neuromorphic computing is a new technique for managing data-intensive operations, requiring memristic devices that store various information states [1]. Research focuses on improving device performance attributes like fast switching speeds, low energy consumption, and endurance. Mass-scalable, inexpensive technologies like inkjet printing are crucial to demonstrating the feasibility of these devices on flexible substrates [2]. 2D materials are easily processed into formulas that can be printed using an inkjet printer and utilized to manufacture memristor devices [3]. Less complicated than transistors, memristors can perform logic and memory tasks with intriguing analog characteristics. Various materials and compositions can be used as active layers in memristors [4]. However, few studies have shown entirely printed 2DMs-based memristors or printed devices using different nanomaterials [5-7]. A low-cost, nonlinear, current-controlled hexagonal boron nitride (hBN) and graphene (GN) inkjet-printed (iJP) memristor is proposed in this work, designed using an Epson XP-960 piezoelectric printer [11].

This study investigates the use of inkjet printing to create a memristor device using nanoparticle-based inks. iJP circuits are a cost-effective, eco-friendly, and power-efficient alternative computing method. A schematic of the memristor is shown in Fig. 1. The memristor is made up of silver nanoparticles printed onto PET film using an Epson XP-960 printer. The channel area is bridged with graphene nanoparticle semiconductor ink. The print process involves printing silver plates with a spacing of 130 µm, aligning the gap with the print head's axis, and examining conductivity. hBN is applied to manage the channel region. The memristor device was analyzed for its memristive behavior, a memory effect that causes the I-V curve to have a loop rather than a single line. The memristor device, a type of hysteretic device, exhibits high non-linearity and varying states, making it ideal for use as reservoirs. The iJP memristors use a unique I-V curve, characterized by a sudden jump in current and gradual increase in positive voltage. The device switches from high resistance to low resistance and then back to high resistance between -40 and 40 volts. The signal has a distinct hysteresis curve, only occurring with a single layer of hBN, while multiple layers mitigate this. The I-V characteristic of the fabricated memristor device is shown in Fig. 2. The memristor, first proposed in 1971, is a device that depends on the time history of current flow or voltage [8]. In 2008, Hewlett Packard Labs demonstrated non-volatile memristive behavior in a Titanium dioxide-based nano-film [9]. Industry has been developing mathematical models to reproduce the complex dynamics of these nano-devices. The mathematical memristor model, based on nonlinear dopant drift, is crucial for investigating the nonlinear dynamics of memristor-based circuits, developing hybrid hardware architectures, and explaining memristive behavior in biological systems. In this work, the memristor model proposed by Yakopcic *et al.* was used to modify parameters to match the voltage and current range of the memristor device, adjusting on-state, off-state, and initial resistances, memristor thickness, and dopant mobility [10]. We also introduced a piece-wise-nonlinear memristor model, and the results for the simulated models are shown in Fig. 3. A primary feature of a memory device is the pinched hysteresis loop. The iJP device's effectiveness as a memory device is demonstrated by the fact that both our experimental and simulated findings display a perfect pinched hysteresis loop.

In conclusion, inkjet printing was used to create a printed memristor device with hBN/GN thin film and Ag electrodes. The device showed good resistive switching behavior and high symmetry, making it suitable for flexible electronics, non-volatile memory, and neuromorphic computing applications.

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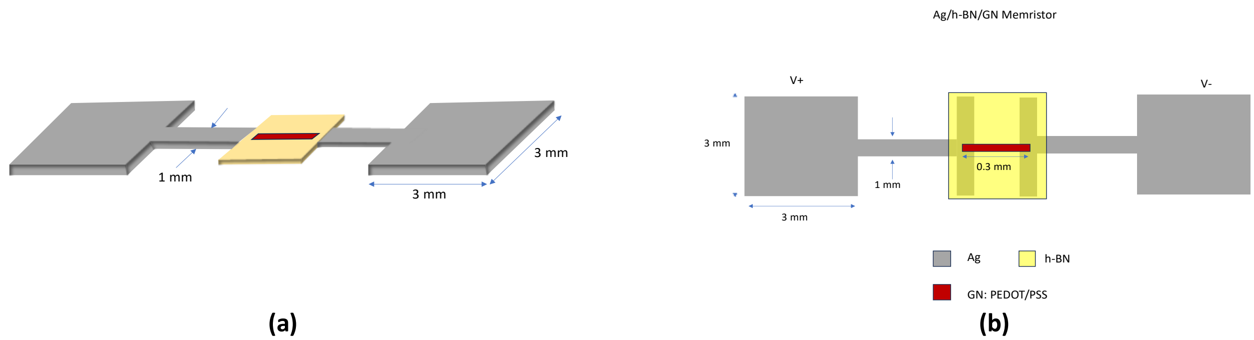

Fig. 1: Schematic of the inkjet-printed (iJP) memristor device. (a) 3D view of the iJP memristor device, and (b) Top view of the iJP memristor device with device dimensions.

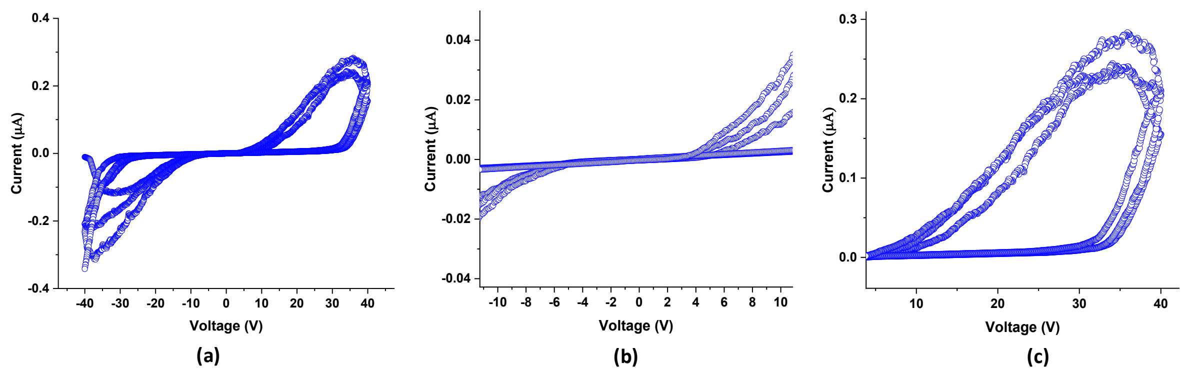

Fig. 2: Measured I-V characteristic of the iJP memristor device. (a) Complete pinched-hysteresis loop, (b) zoomed-in at the pinched area, and (c) the positive hysteresis loop of the iJP memristor device.

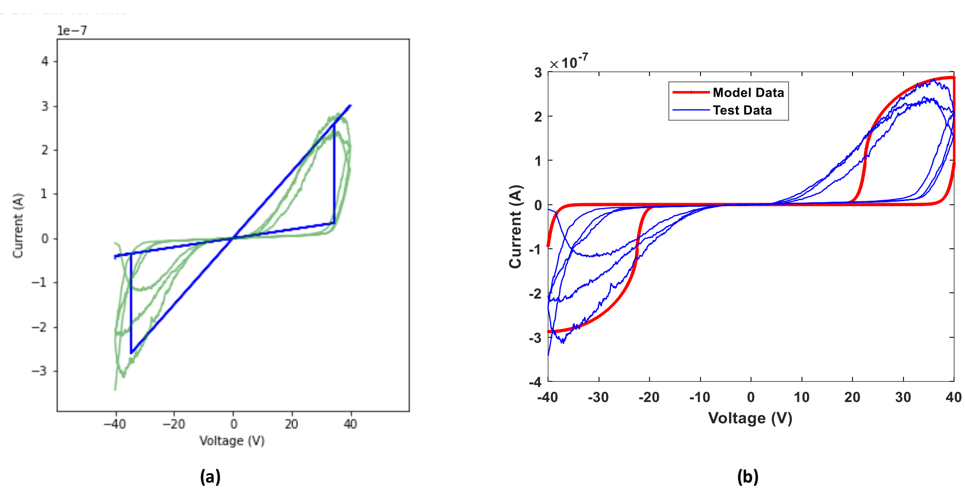

Fig. 3: I-V characteristic of the simulated memristor models. (a) Yakopcic model (blue line) of the iJP memristor device [12], and (b) Our piece-wise-nonlinear model (red line) of the iJP memristor device.