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# Draw Your Electronics: Semiconducting Devices by Hand-Writing ZnO Nanoparticles on Paper

ABSTRACT: The present work reports on the hand writing of electronic circuits on paper based on inorganic oxide semiconductor, exploiting the Pen-on-Paper (PoP) approach. The method relies on the use of a parallel metal plate pen well known from calligraphy applications, which permits controlled deposition of a continuous zinc oxide (ZnO) nanoparticle (NP) matrix on conventional printing paper. The hand-drawn ZnO film exhibits a continuous and uniform surface with a thickness of roughly 1.5 µm, allowing the application as active layers for UV-sensors and field effect transistors (FETs) on paper. Photocurrent generated from the UV radiation reaches values up to 3.2 $mAcm^{-2}$ with switching times in the order of a few seconds. The final written paper transistors, where paper plays simultaneously the role of substrate and dielectric, reached On/ Off current ratios ($I_{On}/I_{Off}$) of about 2 orders of magnitude and field effect mobility close to $5x10^{-3}$ $cm^2V^{-1}s^{-1}$. As a final proof-of-concept a common source amplifier showing clear inverting characteristics was fabricated using a PoP written driving ZnO based transistor and a pencil-drawn track as the load resistance. The reported NP deposition technique can be exploited for several applications where cheap semiconducting devices need to be fabricated at the point of need, in areas as diverse as circuit simulation on paper through biosensors to smart packaging electronics.

## Figures

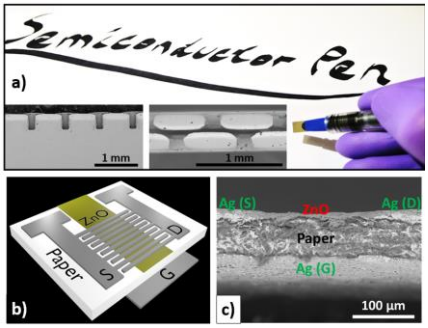


**Figure 1:** General appearance of the parallel metal plate pen and device, with a) showing the calligraphic properties, where the two insets show SEM images of the pen nib in a side and top view, b) shows a schematic view of the final device and c) depicts a cross section SEM image.

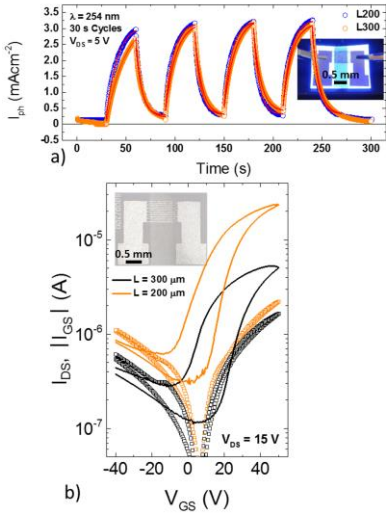


**Figure 2:** Optical and electrical characterization, where a) represents the generated photocurrent (Iph) and b) Transfer curves for two distinct transistors with different channel lengths.