Reliable integrate-and-fire neurons realized with volatile Ag/HfO_2/Pt electrochemical metallization cells

J. Rasbach[(1)], R. W. Ahmad[(1)], N. Ma[(1)], C. Coutinho[(1)], S. Menzel[(1)], S. Hoffmann-Eifert[(1)]

[(1)] Peter-Grünberg-Institut 7, Forschungszentrum Jülich GmbH

Neural integrate-and-fire (IF) functions are considered a key element for the realization of hardware-based neuromorphic computing (NC) concepts. While the emulation of biological synapses with non-volatile memory is a mature research field, the realization of artificial neural functionality with electrical circuits is recently investigated. The integration of threshold switching devices combined with passive integrators, i.e. capacitive elements, enables the implementation of IF neural functionality. Widely used insulator-metal-transition devices have demonstrated high stability in the generated output spike frequency but suffer from significant leakage current in their high resistance state (HRS) due to a low band gap. In contrast, volatile electrochemical metallization cells (vECM) have shown sub-fA leakage current in HRS [1], which makes these devices very interesting for energy efficient NC circuits. However, the switching events that are correlated to the growth and self-dissolution of the metallic filament generally suffer from high variability which is addressed here.

In this study, a comprehensive vECM model is presented which enables the simulation of characteristic *I-V* cycles as well as SET kinetics and relaxation dynamics. The model incorporates the electromotive force (EMF) as a counteracting force providing a deeper understanding in the underlying physical processes in vECM devices. Furthermore, experimental results validate volatile switching of Ag/HfO_2/Pt cells with low variability achieved by designed programming schemes. Finally, the integration of the vECM device in an integrate-and-fire neuron circuit is successfully demonstrated, and potential NC applications are discussed.

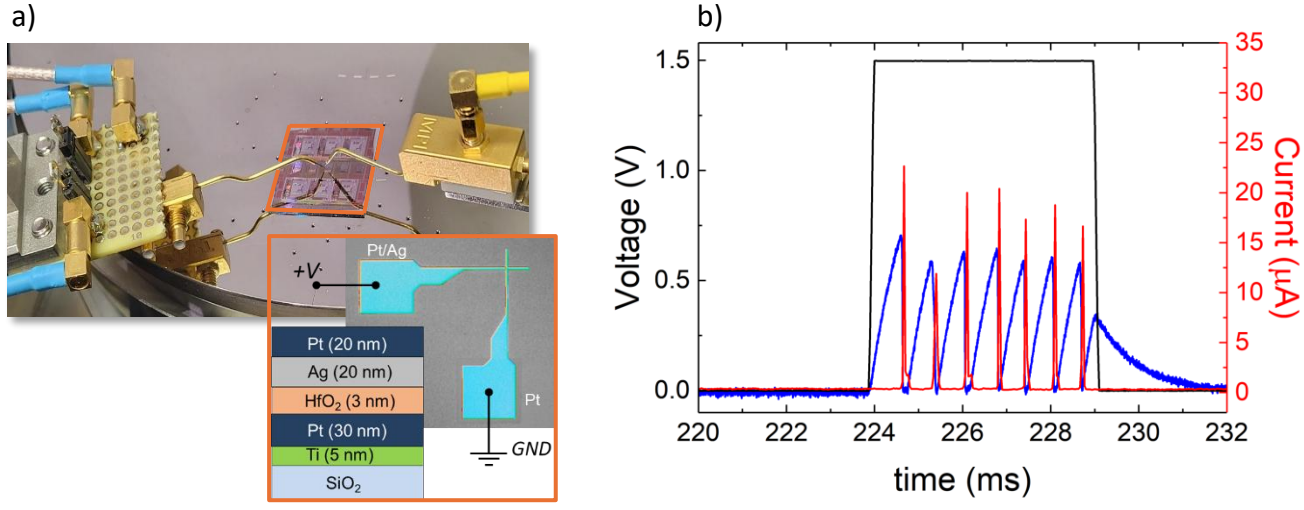

Fig. 1: a) IF neuron circuit with on-chip vECM cell b) Characteristic spiking signal of the circuit

[1] S. A. Chekol, S. Menzel, R. W. Ahmad, R. Waser & S. Hoffmann-Eifert, Adv Funct Mater, 32(15), 2111242, 2022

[2] R. W., Ahmad, S. A. Chekol, J. Rasbach, S. Hoffmann-Eifert & S. Menzel, Adv Intell Syst,, e202501018, 2025