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Concept and modelling of memsensors as two terminal devices with enhanced capabilities in neuromorphic engineering

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We report on memsensors, a class of two terminal devices that combines features of memristive and sensor devices. Apart from a pinched hysteresis (memristive property) and stimulus dependent electrical resistance (sensing property) further properties like dynamic adaptation to an external stimulus emerge. We propose a three component equivalent circuit to model the memsensor electrical behaviour. In this model we find stimulus dependent hysteresis, a delayed response to the sensory signal and adaptation. Stimulus dependent IV hysteresis as a fingerprint of a memsensor device is experimentally shown for memristive ZnO microrods. Adaptation in memsensor devices as found in our simulations resembles striking similarities to the biology. Especially the stimulus dependency of the IV hysteresis and the adaptation to external stimuli are superior features for application of memsensors in neuromorphic engineering. Based on the simulations and experimental findings we propose design rules for memsensors that will facilitate further research on memsensitive systems.

Since the postulation of the experimental realization of a memristor device in 2008[1], there has been an increased effort in understanding and modelling memristive (resistive) switching for a broad variety of device classes[2–4]. Up to now (2018) an increasing group of concepts for memristive devices with sensing behaviour has been reported, typically based on metal oxide or semiconductor nanostructures with sensing of temperature[5], (UV)-light[6–9], gases[10,11], magnetic field[7], mechanical response[12], biomolecules[13–15] or pH[16,17]. However, a systematic treatment of the junction between memristive and sensitive devices is still missing.

In this work we report on the concept of memsensors, a class of two terminal electronic devices that combine the properties of memristive switching and sensing properties. By thoughtfully designing electronic devices with both, a sensing part (stimulus dependent resistance) and a memristive part (pinched hysteresis and memory) it is possible to make use of their enhanced capabilities. In classical electronics respective controlling theory, sensors that show a hysteresis are typically regarded as a poor sensing device. However, features like adaptation and forgetting are essential for efficient learning in biological systems such as neuronal networks[18,19]. In memsensors, the combination of sensing and memory resembles the dynamic response of biological systems to environmental stimuli. One example is adaptation: the response to a constant excitation decreases asymptotically over time, the system accommodates to the constant stimulus. After reducing the stimulus for a long period, the system recovers its initial sensitivity. Adaptation is key for efficient use of neuronal capabilities[18]. First indications for adaptation in memsensor devices, although not specifically mentioned, can be found in the work of Chiolerio *et al.* and Lupan *et al.*[6,11] Although over the past years there has been an increasing number of detailed reports on memristive switching devices combined with sensing capabilities, to the best of our knowledge a systematic description of the concept of memsensors as well as the link to adaptation is still missing.

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