

In Situ TEM Biasing and Heating of Neuromorphic Gold Nanogranular Nanofilms Showing Resistive Switching

Prof. Andrea Falqui¹, Mr. Alberto Casu¹, Mr. Paolo Milani¹, Ms. Angelica Chiodoni², Mr. Yuri Ivanov³, Mr. Giorgio Divitini³

¹University of Milan, Department of Physics, Milan, Italy, ²Center for Sustainable Future Technologies @PoliTo, Istituto Italiano di Tecnologia, Turin, Italy, ³Electron Spectroscopy and Nanoscopy, Istituto Italiano di Tecnologia, Genoa, Italy

Background incl. aims

Nanogranular gold films, when prepared by supersonic cluster beam deposition with a thickness just above the electrical percolation threshold, exhibit highly branched structure with a neuromorphic behavior reminiscent of biological neural networks, including resistive switching and adaptation. Such characteristics position these materials as viable substrates for neuromorphic computing. Despite their potential, the understanding of the underlying phenomena has been limited to electrical measurements and theoretical speculation. The objective of this study was to visually elucidate the morphological transformations that occur at the micro- and nanoscale within these films during electrical stimulation and to assess how these changes correlate with neuromorphic functionality.

Methods

Gold nanogranular films were deposited at approximately 17 nm thickness to balance electrical conductivity with TEM imaging suitability. These films were then subjected to in situ biasing within a two-electrode configuration. High temporal resolution imaging was conducted using a CMOS direct detection camera, operating at a controlled low electron dose. The morphology of the entire area between electrodes was observed during sequential electrical stimulations—first across a voltage ramp and then at a constant voltage. Additionally, in situ heating TEM imaging was applied, observing the films under thermal stress at both high resolution and low magnification.

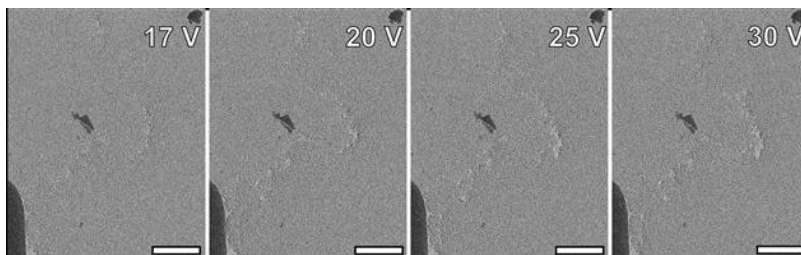
Results

Initial in situ biasing caused the localized de-percolation effect shown in figure [1], and characterized by the retraction of gold branches without mass loss, leading to the formation of isolated gold islands. This morphological adaptation was highly localized and accompanied by the development of small, dense gold structures. Upon global thermal stimulation, the films underwent a more extensive de-percolation, resulting in the creation of distinct, polycrystalline gold islands across the whole heating substrate. This behavior is akin to that observed in atom-assembled gold films. The in situ TEM imaging revealed the likely occurrence of extremely intense and localized hot spots, whose temperature and extent appear to grow with increased voltage and may induce localized melting, even possibly capable of disrupting the amorphous silicon nitride substrate when the highest voltage and temperature are reached [1].

Conclusions

The study presents a novel visual insight into the morphological dynamics of nanogranular gold films under electrical and thermal stimuli, suggesting that intense, localized hot spots may play a critical role in neuromorphic behavior. The findings highlight the need for further exploration of the local temperature within these hot spots, the role of electromigration and Joule heating, and the impact of the substrate on the film's behavior. In situ TEM imaging has proven invaluable in expanding our understanding of the physical phenomena driving the unique electrical characteristics of metal nanogranular films, offering implications for the advancement of materials with neuromorphic properties.

Graphic:



Keywords:

in-situ biasing and heating TEM

Reference:

[1] A. Casu, Angelica Chiodoni, Yuri P. Ivanov, Giorgio Divitini, Paolo Milani,* and Andrea Falqui*.

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