2D Chalcogenides: Anharmonic Phonon Behavior, Cryogenic Sensors, and Energy-Efficient Memristors

A.C. Galca[1], A.T. Buruiana[1], A.E. Bocirnea[1], C. Mihai[1], F. Sava[1], A. Velea[1]

[1] *National Institute of Materials Physics, Atomistilor 405A, 077125 Magurele, Romania*

ac_galca@infim.ro

This work explores the fascinating realm of 2D chalcogenide materials. Chalcogenides, such as SnSe, Cr-Se, WS_2, and MoS_2, possess unique electronic and optical properties due to their atomically thin structure and strong interlayer bonding. These materials offer exciting opportunities for applications ranging from electronics to optoelectronics, energy conversion, and beyond. Discerning the fundamental characteristics and exploring the potential of 2D chalcogenide materials pave the way for advancements in various fields, including nanoelectronics, cryogenics, and emerging technologies.

Understanding the phonon anharmonicity and temperature-dependent behavior in 2D materials is crucial for the development of efficient memory elements and memristor devices. Among these materials, orthorhombic SnSe nanoflakes have garnered significant interest due to their potential applications in novel devices. SnSe nanoflakes with a thickness of less than 100 nm, oriented along the [100] crystal axis, were obtained using physical vapor transport at atmospheric pressure [1]. To investigate the anharmonic phonon behavior in SnSe nanoflakes, polarization-resolved Raman spectroscopy was performed at a temperature of 5 K. The frequencies and linewidths of Raman modes in tin selenide were analyzed and fitted to the anharmonic phonon coupling theory. The findings indicate that both two and three order processes contribute to the phonon decay in tin selenide. Additionally, the temperature dependence of the Raman shift and linewidth reveals the strong anisotropy of SnSe nanoflakes.

The development of micrometer-sized hexagonal chromium selenide (Cr-Se) flakes for cryogenic temperature sensing [2] is also part of this work. These flakes were synthesized using a physical vapor transport method and characterized using scanning electron microscopy, energy dispersive X-ray spectrometry, and X-ray photoelectron spectroscopy. By transferring the flakes onto Au contacts using a dry transfer method, resistivity measurements were performed in a temperature range from 7 K to 300 K. The excellent fit quality of the collected data allowed for extrapolation of resistivity values, demonstrating the logarithmic sensitivity of the sensor for a large domain of cryogenic temperatures.

The fabrication and characterization of energy-efficient memristive devices using liquid-exfoliated 2D WS_2 and MoS_2 nanosheets [3] will also be presented. The nanosheets were enriched in monolayers through a cascade centrifugation method and integrated into lateral devices with electrochemically inert electrodes. The conventional spectroscopy measurements are used to determine the mean size and mean thickness of the nanosheets. The resulting memristive devices exhibited non-volatile resistive switching behavior with remarkably low energy consumption, and can contribute to the realization of ultra-low-power and high-performance neuromorphic computing applications.

Acknowledgement: The authors acknowledge the financial support of the Romanian Ministry of Research, Innovation and Digitalization in the framework of the M-ERA.NET 109/2019 (ERANET-M.-2D-SPIN-MEM) project, Core Program PN19-03 and Core Program Project PC3-PN23080303.

[1] A.T. Buruiana, A.E. Bocirnea, A.C. Kuncser, T. Tite, C. Mihai, N. Zawadzka, K. Olkowska-Pucko, Ł. Kipczak, A. Babiński, M.R. Molas, A. Velea, A.C. Galca, Applied Surface Science, **599**, 153983 (2022)

[2] A.T. Buruiana, F. Sava, N. Iacob, E. Matei, A.E. Bocirnea, M. Onea, A.C. Galca, C. Mihai, A. Velea, V. Kuncser, Sensors, **21**, 8084 (2021)

[3] C. Mihai, F. Sava, A. C. Galca, A. Velea, AIP Advances, **10**, 025102 (2020)