Humboldt-Kolleg NANO-2024: “Quo Vadis – Ethics of the Scientific Research”
Chişinău, Republic of Moldova, 15.-18. April 2024

Technology of fabrication and applications of 3D micro-nano-architectures based on aero-GaN

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Introduction

Aeromaterials, such as aerogels, represent three-dimensional ultra-lightweight extra-porous materials formed by randomly distributed networks of nanostructures having different sizes and shapes, such as nanowires, nanotubes, or nanosheets. There is a rather limited number of materials that can be prepared as aeromaterials, but this number is continuously increasing, especially for carbon-based nanomaterials, such as carbon nanotubes, graphene, aerographite, etc.

Aerogalnite (Aero-Gallium Nitride, Aero-GaN, AGaN) is a synthetic material consisting of networks of GaN interconnected microtubes. Due to the fact that the microtubes walls thickness is just several nanometers, the material is ultra-lightweight with a density of around 10 mg/cm^3, being among the lightest synthetic materials [1]. Aerogalnite is a pale-yellow freestanding highly porous, mechanically flexible and stretchable inorganic nanomaterial that is both hydrophobic and hydrophilic at the same time. Rolling a water droplet onto a bed of GaN hollow tetrapods results in the formation of a liquid marble with the entire surface covered with GaN aerotetrapods. GaN has been claimed to be a “next silicon” because of the extraordinary development of various applications of this semiconductor compound in highfrequency devices, power electronics, and optoelectronics.

The continuous development of nanotechnology in the medical field demands new multifunctional materials, which should be compatible with both electronics and semiconductor technology, as well as with living organisms and highly chemically active environments. In the last two decades, research efforts have been undertaken to develop self-propelled liquid marbles exhibiting translational motion, rotation or their combination, self-propulsion being reached by adding volatile substances to the core liquid.

Methods

By using the hydride vapor phase epitaxy (HVPE) method, nanometric-thin layers of GaN were succesfully grown on sacrificial structures based on zinc oxide microtetrapods (ZnO). During the growth process and afterwards the ZnO layer is being decomposed, while the GaN coat preserves the outer shape of initial structures. In the end, hollow nano-spheres and micro-tetrapods based on GaN were obtained. The high quality of material is demonstrated by using electron microscopy techniques.

Results

The GaN tubular microstructures, with diameter of 2-10 µm, the length from 20 to 100 µm and the wall thickness several tens of nanometers, show interesting microfluidic properties. A pellet of micro-tubes and hollow micro-tetrapods exhibit hydrophilicity under tension and hydrophobicity when compressed against water [1]. The hydrophilicity is attributed to the nanoscale free ends and internal walls of the tetrapod arms, which consist of ultrathin ZnO layer, and the hydrophobicity to the external GaN walls. Self-assembling tetrapods on the water surface enabled us to develop a proof-of-concept device, namely of stretchable and highly energy efficient self-propelled liquid marbles exhibiting fast velocity of rotation, pulsed rotation [2] and exceptional mechanical robustness. These findings on Gallium Nitride nanostructures have great potential to the development of innovative biomedical engineering applications e.g. the development of cellular based therapy concept, remotely controlled tissue/organs engineering, energy-efficient self-propelled micro-electro-mechanical structures, etc.

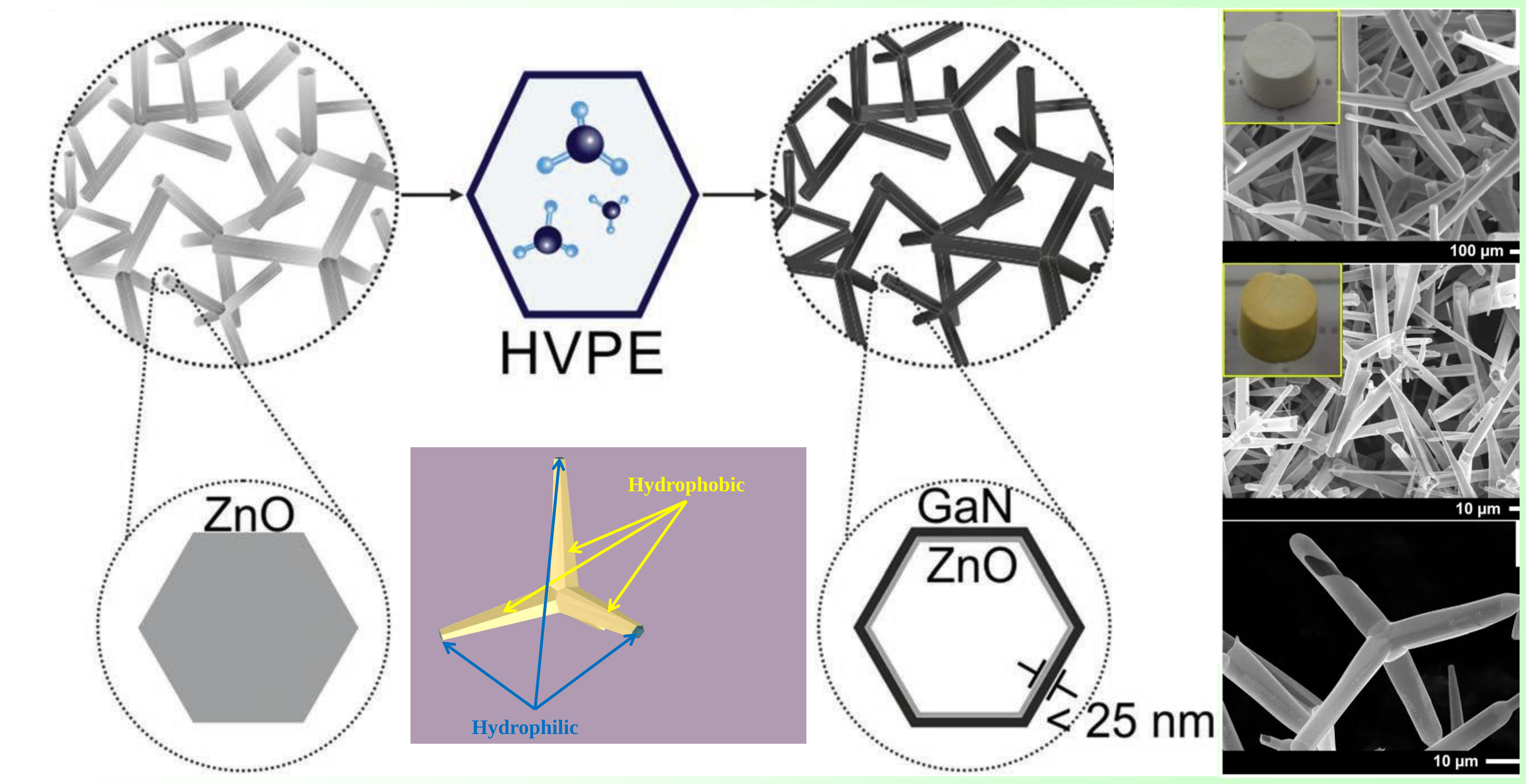

Fig. 1. Schematic representation for Aero-GaN obtaining process via HVPE deposition of thin layers of GaN on sacrificial layer of ZnO

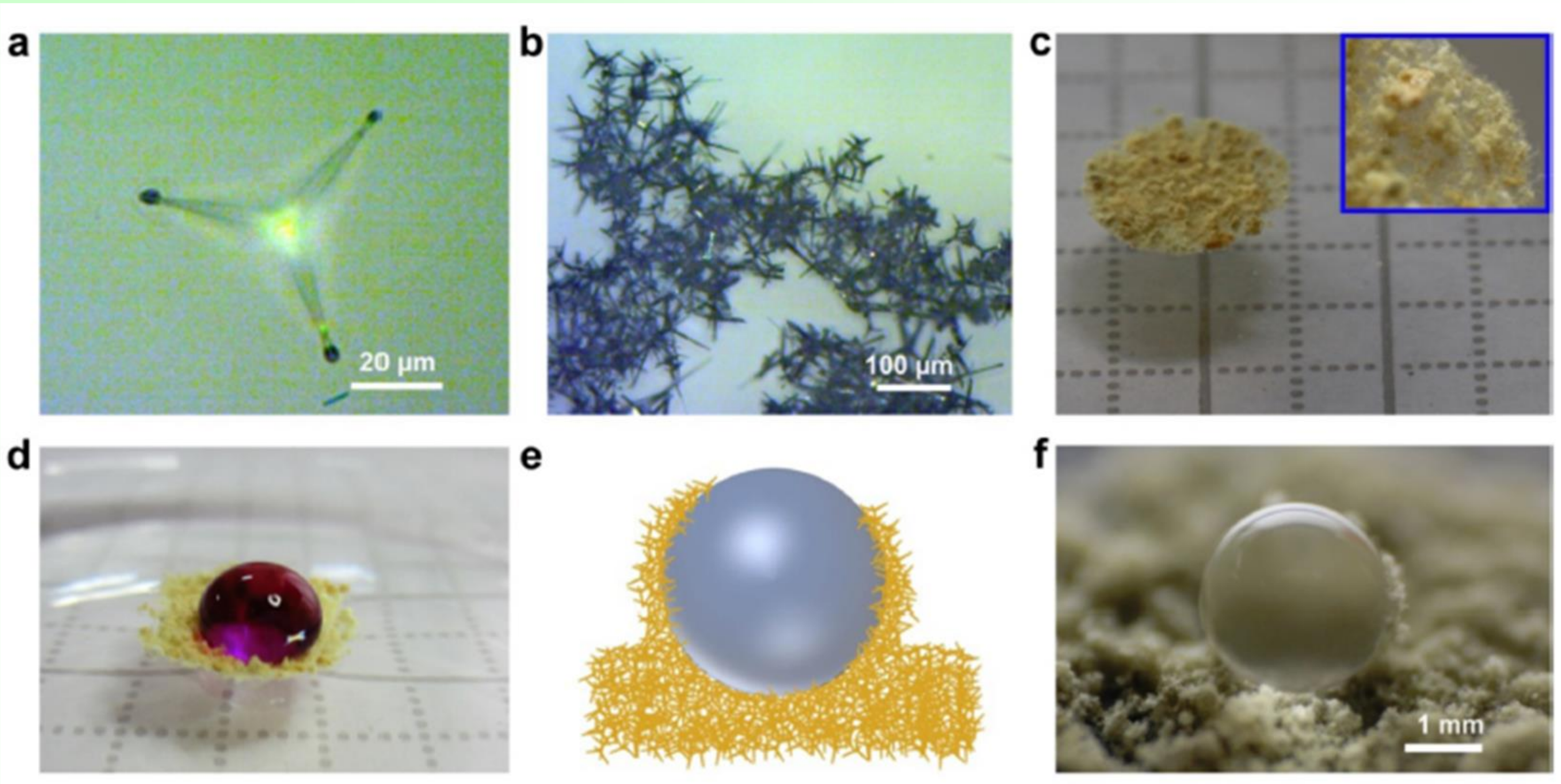

Fig. 4. An individual tetrapod (a), a network of interpenetrating tetrapods (b) and an AGaN raft (c) floating on water surface; (d) illustrates a raft loaded by a drop of coloured water; (e) schematic illustration of a water droplet encircled by floating AGaN microtetrapods; (f) rolling a water droplet onto a bed of AGaN microtetrapods;

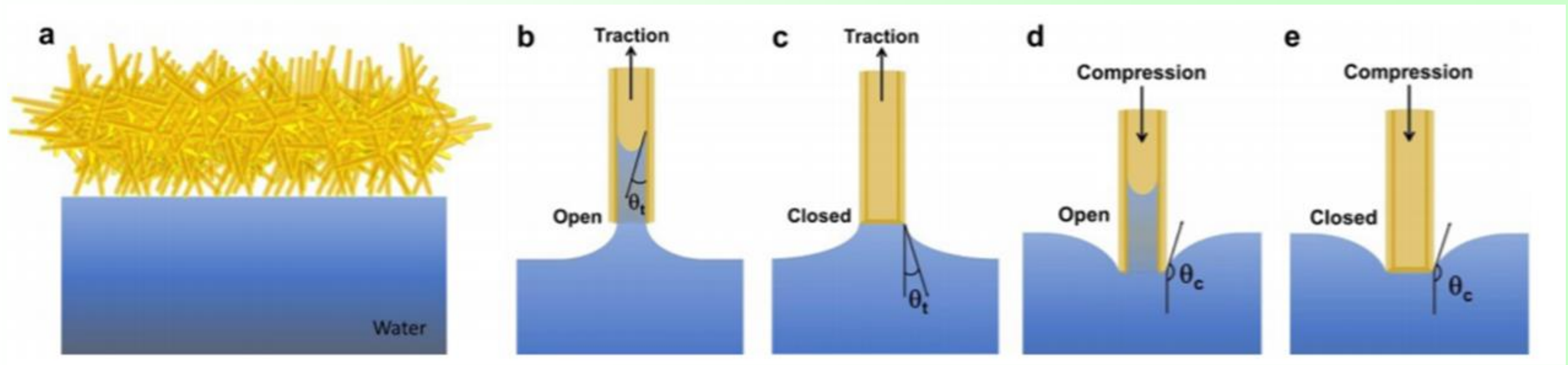

Fig. 2. (a) Illustration of a AGaN raft floating on water. (b-e) Schematic illustration of the combination of hydrophilic and hydrophobic properties inherent to closed or open ends of GaN aerotetrapods in traction or compression.

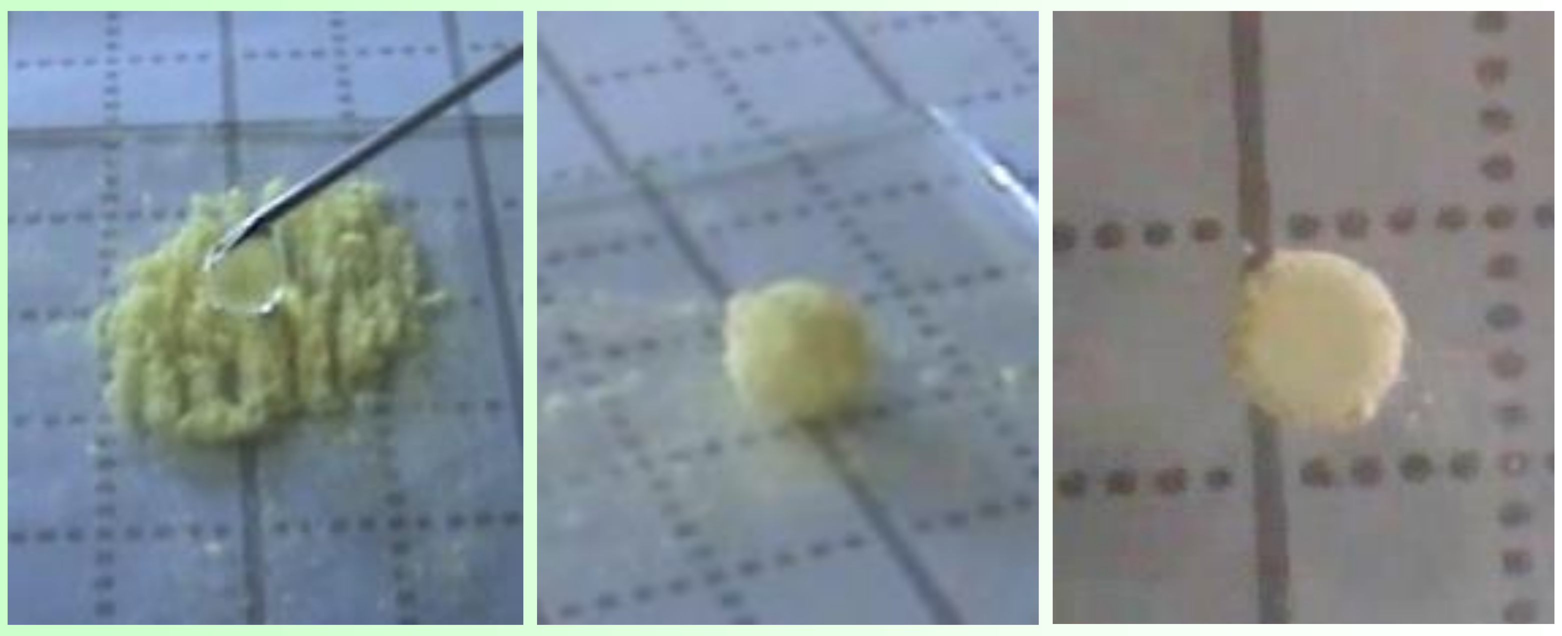

Fig. 5. Aero-GaN Liquid Marble: (a) formation of aero-GaN liquid marble; (a) digi-tal image of an aero-GaN LM on glass; (c) Uniaxial deformation of the aero-GaN Liquid Marble between two glass plates

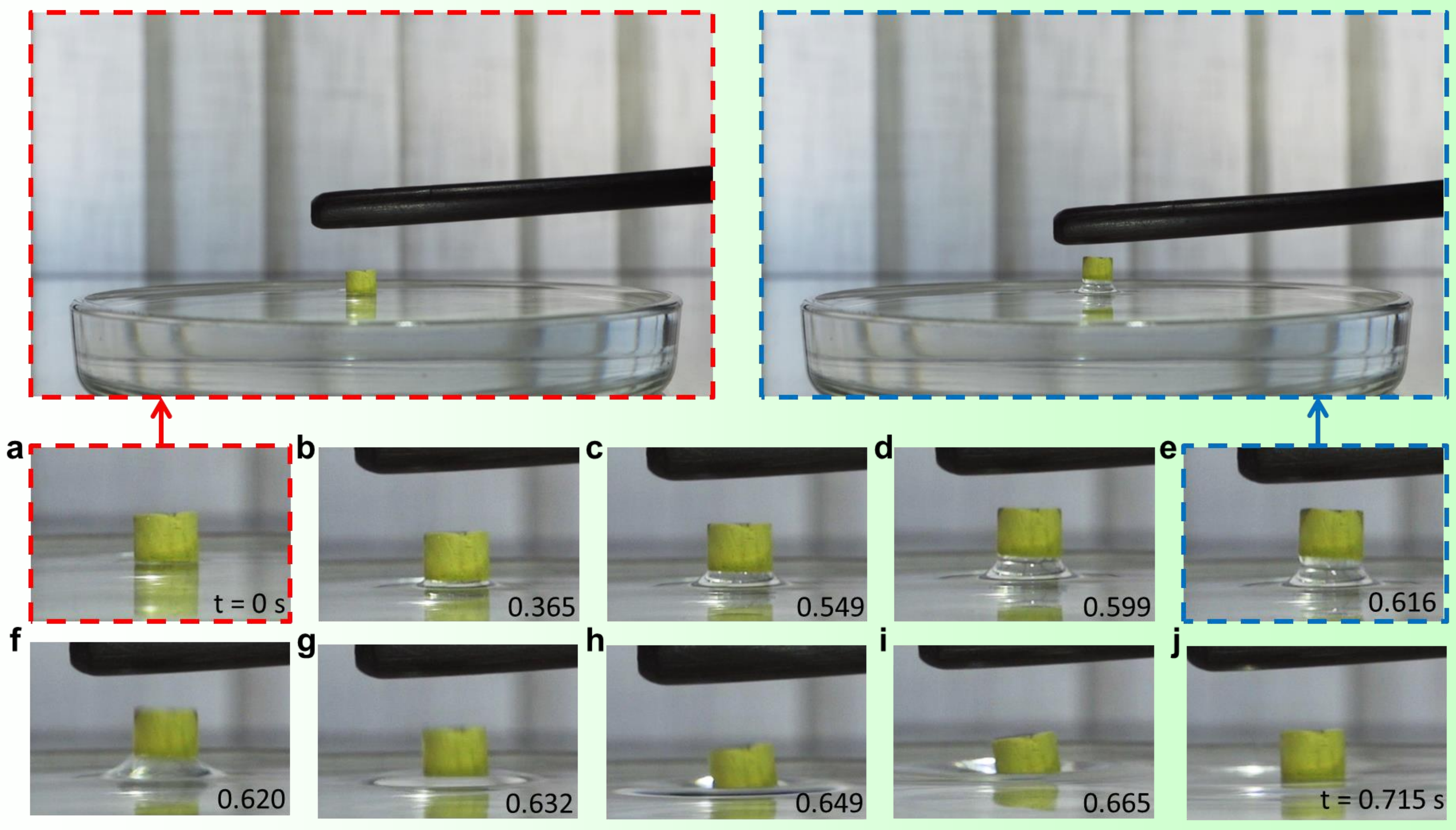

Fig. 3. Demonstration of hydrophilic dewetting of Aero-GaN

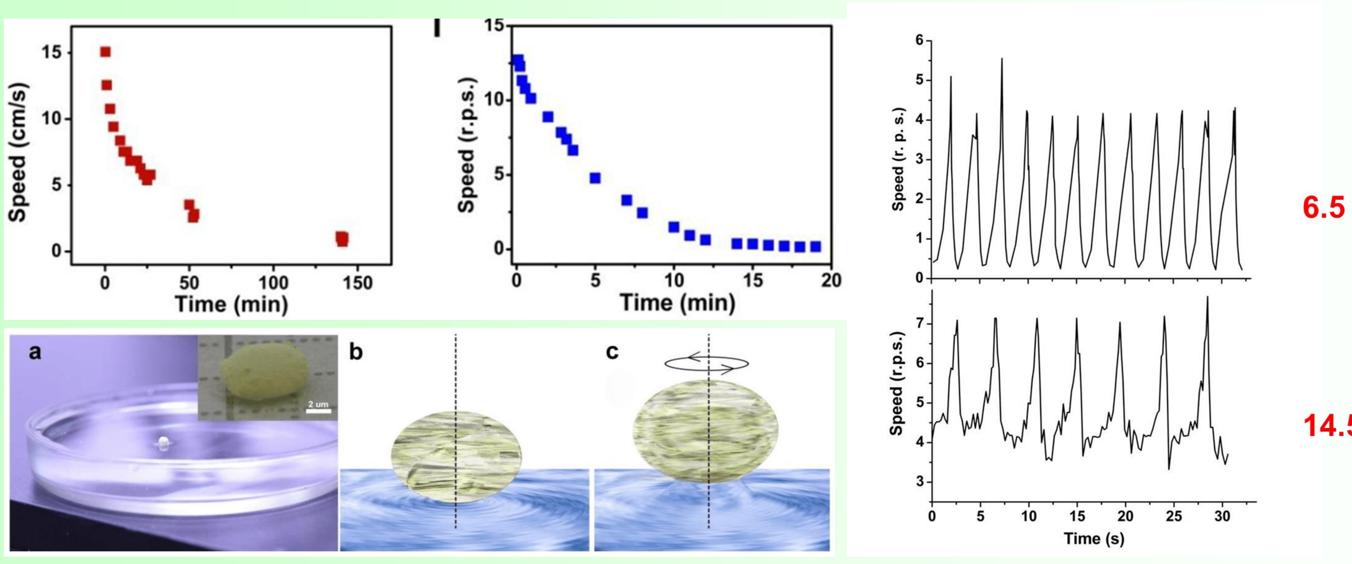

Fig. 6. Graphical representation of liquid marble autopropulsion on water. Pulsed rotation of liquid marbles based on aero-GaN. (**a**) Liquid marble floating on water, where the inset represents a digital picture of an elongated liquid marble. (**b**) Schematic interpretation of the liquid marble on the water surface; (**c**) the same liquid marble when rotating at high velocities, leading to the formation of a water column.

References

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[2] T. Braniste, V. Ciobanu, F. Schütt, H. Mimura, S. Raevschi, R. Adelung, N. M. Pugno and I. Tiginyanu. Self-propelled aero-GaN based liquid marbles exhibiting pulsed rotation on the water surface, Materials, Vol. 14, no 7, 5086, 2021.

The author acknowledges the financial support from the National Agency of Research and Development in frame of the Postdoctoral Project „Obținerea și caracterizarea structurilor tridimensionale cu elemente bidimensionale în baza compușilor semiconductori” G.A. No. 24.00208.5007.01/PDI.