Laser direct writing of Ga2O3/liquid metal-based flexible humidity sensors

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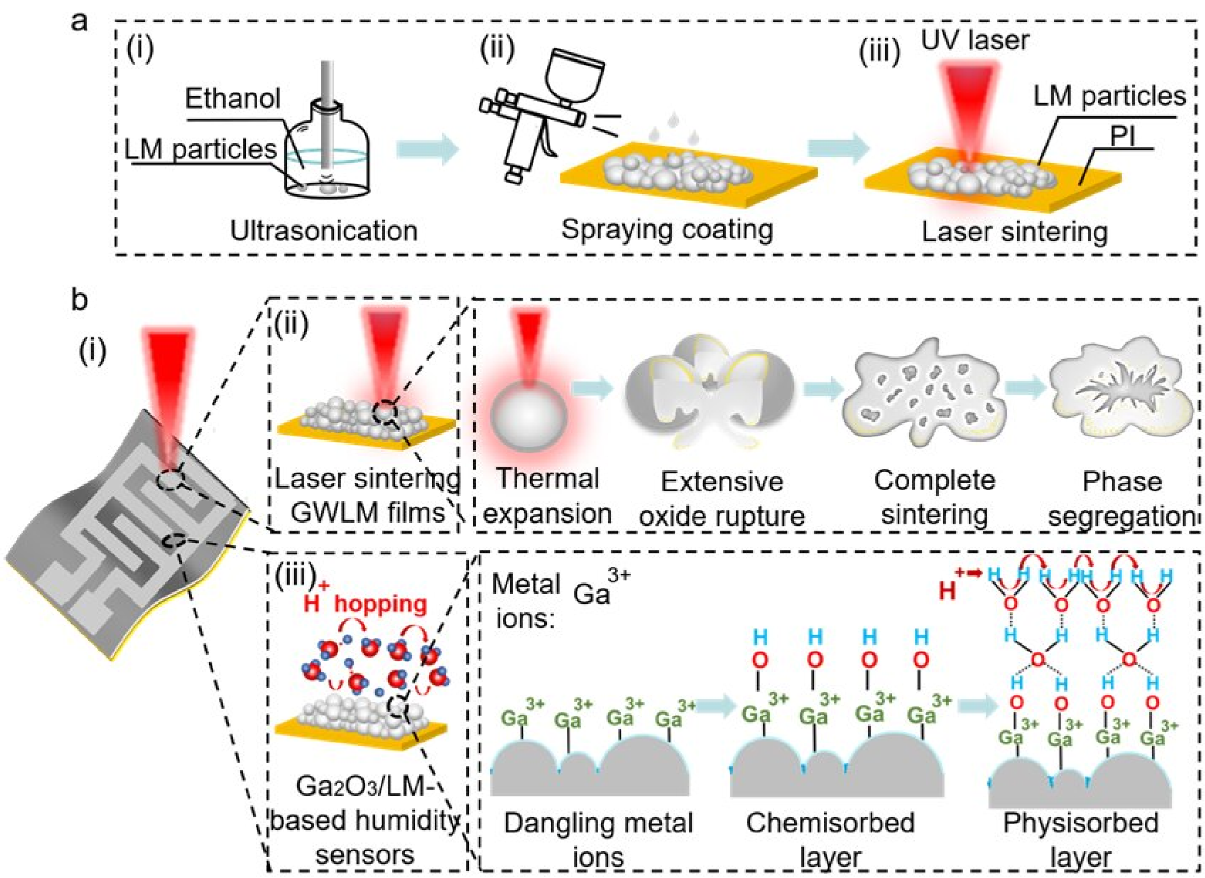
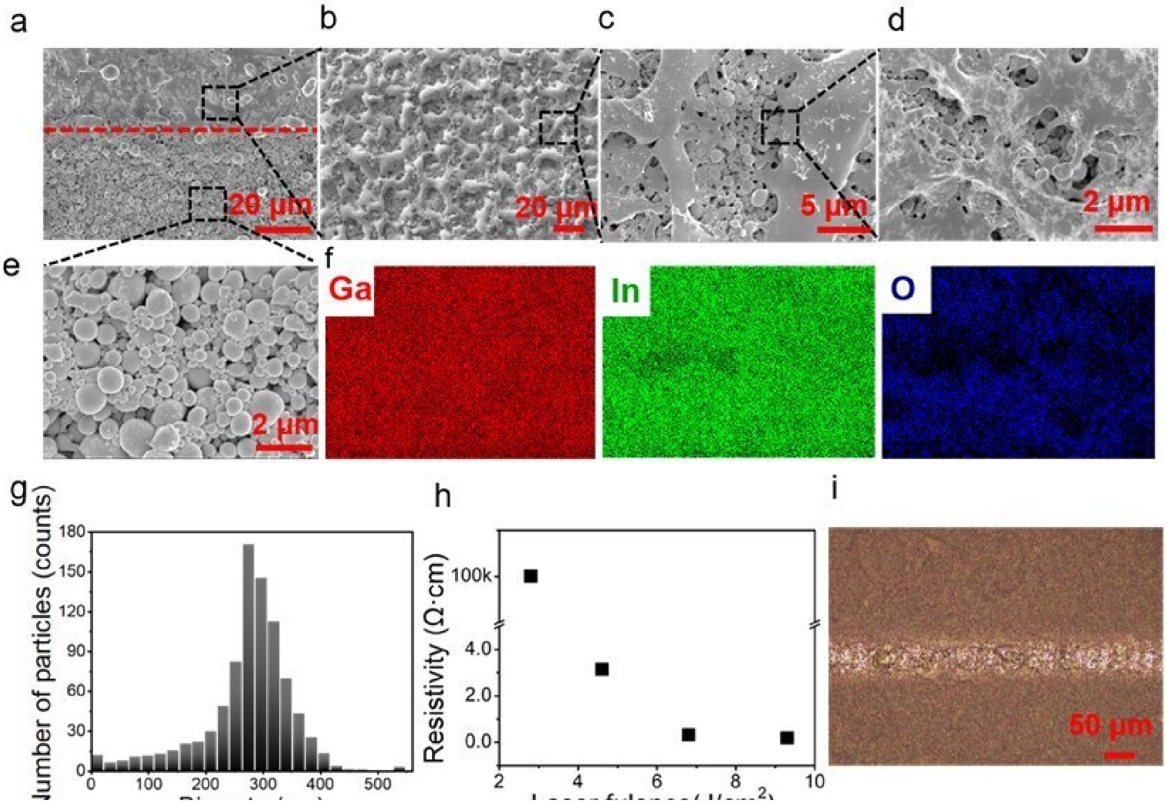


Design and fabrication of flexible capacitive humidity sensors. (a) Fabrication processes of flexible Ga_2O_3/LM humidity sensors, including ultrasonication, spraying coating and laser sintering. (b) Schematic of the mechanism to form GWLM films by laser sintering and the sensing mechanism of Ga_2O_3/LM-based humidity sensors. Credit: *Opto-Electronic Advances* (2023). DOI: 10.29026/oea.2023.220172

Recent studies in emerging flexible humidity sensors have achieved great developments in advanced manufacturing methods, as well as innovative applications including human health care detection, plant health management and noncontact human-machine interfaces. Capacitive-type humidity sensors have gained much attention due to reliable humidity sensing performance, low power consumption and facile structural designs. Generally, the performance of a capacitive humidity sensor is strongly correlated with the dielectric permittivity of functional materials between sensing electrodes.

Up to now, various active materials have been investigated as flexible capacitive humidity sensors, such as carbon materials, metal oxides, metal sulfides, and polymers. Similarly, they are typically endowed with large exposed surface areas and rich active sites to interact with water molecules. Ga_2O_3, as a potential metal oxide with high exposed hydrophilic groups, has been employed as an active material for capacitive humidity sensors.

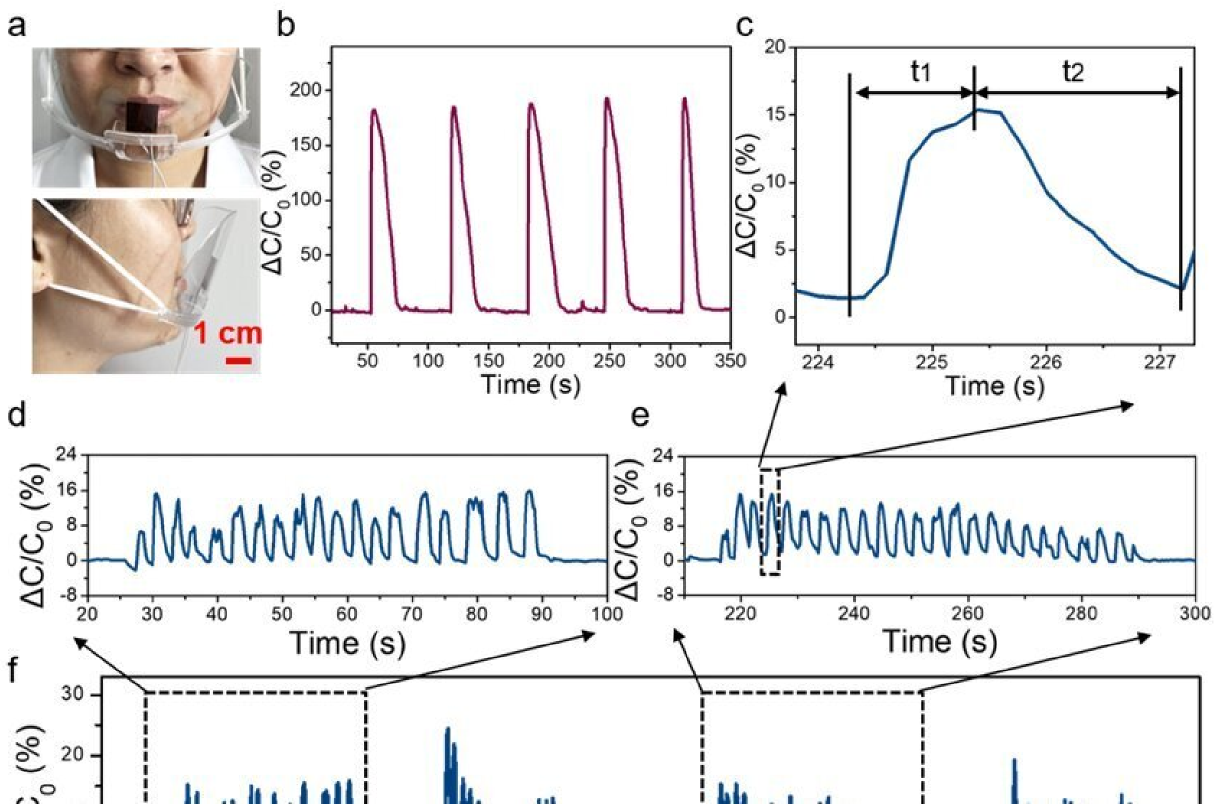
Traditional fabrication techniques to obtain Ga_2O_3-based humidity sensors mainly involve chemical vapor deposition, thermal treatment, and hydrothermal methods. Nevertheless, these methods usually require high annealing temperature, complicated fabrication procedures as well as various material systems, hindering their practical applications.



Characterizations of flexible humidity sensors. SEM images of GWLM (a-d) with and (a, e) without laser sintering. (f) EDX images of the Ga, In, and O distributions. (g) Histogram of diameter size distribution for the un-sintered GWLM particles on the PI film. (h) Resistivity of the laser induced conductive GWLM paths at different laser fluences. (i) The minimum resolution of sintered LM path at a laser fluence of 9.4 J/cm2. (j)-(l) Schematics of Ga_2O_3/LM-based humidity sensors with various fabrication parameters (i.e. widths and lengths of electrodes, UV laser fluence) (top). Cycle measurements of Ga_2O_3/LM-based humidity sensors by periodically varying the humidity from 30% RH to 95% RH (bottom). Credit: *Opto-Electronic Advances* (2023). DOI: 10.29026/oea.2023.220172

Digital laser direct writing is a rapid and environmental-friendly manufacturing approach to generating functional micro/nano-structures or directly creating sensitive nanomaterials with high precision. Based on laser-matter interactions, via judiciously selecting the appropriate laser processing parameters, a variety of innovative flexible sensors, such as physical, chemical and physiological sensors have been demonstrated.

The typical strategies usually rely on the laser direct writing of electrodes, followed by the deposition of moisture sensitive nanomaterials, such as carbon or metal sulfides-based materials, on the top of electrodes. However, this leads to multiple complex procedures. Therefore, a facile and simple approach to developing thin film-based humidity sensor is still required.



(a) Photos of a humidity sensor on a commercial mask worn on the subject's face. (b) Human respiration test of a subject by mouth at a rest state. (c) Response and recovery time of the sensor. (d)-(f) Real-time monitoring of respiratory rate by nose of a subject at a rest state. Real-time monitoring of palm moisture while (g) drinking hot water and (h) exercising. Credit: *Opto-Electronic Advances* (2023). DOI: 10.29026/oea.2023.220172

In this new work, published in *Opto-Electronic Advances*, a wearable capacitive-type Ga_2O_3/liquid metal-based humidity sensor is demonstrated by a one-step laser direct writing technique. Due to the photothermal effect of laser, the Ga_2O_3-wrapped liquid metal nanoparticles can be selectively sintered and converted from insulative to conductive traces with a resistivity of 0.19 Ω·cm, while the untreated regions serve as active sensing layers in response to moisture changes.

Under 95% relative humidity, the humidity sensor displays a highly stable performance along with rapid response and recover time. Utilizing these superior properties, the Ga_2O_3/liquid metal-based humidity sensor is able to monitor human respiration rate, as well as skin moisture of the palm under different physiological states for health care monitoring.

More information: Songya Cui et al, Laser direct writing of Ga_2O_3/liquid metal-based flexible humidity sensors, *Opto-Electronic Advances* (2023). DOI: 10.29026/oea.2023.220172

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