

Sensor-on-LED: Visible-Light-Activated Gas Sensing Using Flame Spray Pyrolysis

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Summary:

Visible-light-activated gas sensors require not only compact optical integration, but also sensing-layer fabrication compatible with wafer-level processing. In this work, we focus on the engineering of porous WO_{3-x} sensing layers directly deposited onto LED microchip arrays via flame spray pyrolysis (FSP). Using a 460 nm sensor-on-LED platform as a model system, we investigate how FSP deposition conditions define film thickness and surface chemistry. The resulting highly porous WO_{3-x} films enable efficient gas access, visible-light interaction, and scalable wafer-level integration without post-treatment.

Keywords: Flame spray pyrolysis, Visible-light-activation, LED-integration, Gas sensors, wafer-level.

Motivation

The physical separation between the light source and the gas-sensing layer remains a major limitation in visible-light-activated gas sensors, as it increases device complexity, optical losses, and integration challenges. Direct sensor-on-LED architectures offer a compact solution, but their practical implementation is often constrained by conventional SMOX sensing-layer fabrication processes, which may involve high-temperature post-treatment, extreme pH conditions, or mechanical stress. These factors can degrade LED luminescence and shorten device lifetime.

In this work, flame spray pyrolysis (FSP) provides a device-compatible direct-deposition route for porous WO_{3-x} layers on LED microchips. More importantly, FSP is not only an integration method, but also a processing tool for tailoring film thickness, nanoparticle-network structure, surface defect chemistry, and gas accessibility, all of which directly influence visible-light interaction and gas-sensing performance.

Method

Here, A GaN-based LED array was fabricated on one side of a 2-inch sapphire wafer, and WO_{3-x} gas sensing layer was deposited on the other side via FSP.

LED layer: GaN-based LED epitaxial layers, including an AlN buffer layer, Si-doped n -GaN layer, InGaN/GaN multiple quantum wells (MQWs), p -AlGaIn electron blocking layer (EBL)

and p -GaN layer were orderly grown on one side of a (0001) sapphire wafer via metal–organic chemical vapour deposition (MOCVD). Then, an array of flip-chip structures was fabricated on the GaN epitaxial layers. The size of each unit in the array was $600\ \mu\text{m} \times 600\ \mu\text{m}$, and the wavelength of the LED is 460 nm. By precisely adjusting the proportion of indium (In) within the material, the wavelength of the emitted light can be continuously and precisely controlled from the violet to the green range. After flip-chip fabrication, the sapphire substrate was thinned from the other side using mechanical grinding and subsequent chemical-mechanical polishing (CMP). This process reduced the wafer thickness to $150\ \mu\text{m}$ while removing grinding-induced surface damage and maintaining optical and mechanical quality for further integration.

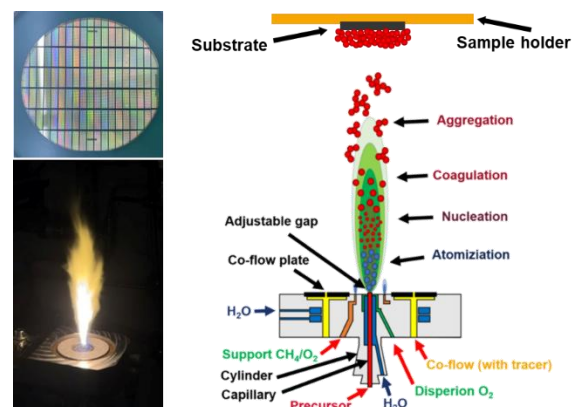


Fig. 1. FSP setup for the direct deposition of a porous sensing layer onto LED chips.

Gas sensing layer: Au interdigital electrodes were deposited on the opposite side of the sapphire wafer via photolithography and electron beam evaporation (EBE). The sensing layer was then directly deposited on top of the Au electrodes via FSP. During the deposition process, as shown in Fig. 1, the sample holder was placed at a defined height above the nozzle, and circulating cooling water was used to maintain the sapphire substrate temperature at approximately 120 °C. By adjusting FSP parameters such as precursor concentration, deposition time, methane/oxygen ratio, and dispersion oxygen flow rate, the WO_{3-x} film thickness, oxygen stoichiometry of WO_{3-x} surface defect chemistry can be tailored, thereby influencing light–matter interaction and gas sensing performance under visible-light excitation.

Results

As shown in Figure 2, The FSP-derived WO_{3-x} sensing layers formed highly porous nanoparticle networks directly on the LED microchip without post-deposition heat treatment. The films exhibited high crystallinity, approximately 97% porosity, nanoparticle sizes of about 15 nm, and a specific surface area of around $60 \text{ m}^2 \text{ g}^{-1}$. By adjusting FSP parameters, the film thickness, oxygen stoichiometry and defect-related surface chemistry could be tuned. These features regulate optical accessibility and charge-transport pathways under visible light illumination, thereby influencing visible-light-activated gas-sensing

performance. The results demonstrate that FSP enables both wafer-level integration and process-controlled engineering of WO_{3-x} sensing layers for compact sensor-on-LED platforms.

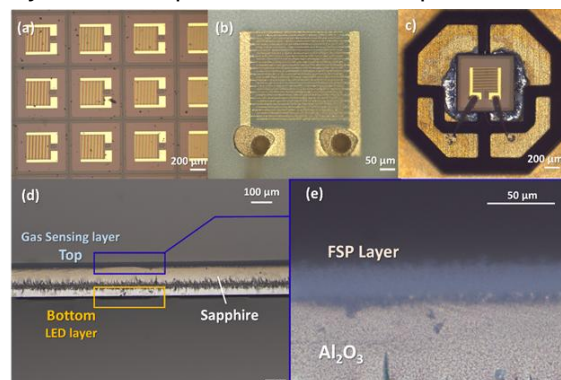


Fig. 2. Microscopy images of the (a) transparent gas sensing layer and Au interdigital electrodes (electrode spacing: 10 μm) after FSP, (b) and (c) after bonding; Cross-sectional microscopy images of (d) integrated microchip, (e) WO_3 gas-sensing layer by FSP.

References

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