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Direct laser patterning of a gas sensor on flexible substrate

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Abstract

Flexible gas sensor fabricated by direct laser patterning and its gas sensing properties towards ozone and ammonia are reported. The flexible platform consists in Ti/Pt interdigitated electrodes for gas detection and a microheater device. The platform validation has been realized by thermal simulation and its electrical properties have been also studied. The gas sensing properties were investigated using a commercial ink of ZnO nanoparticles at several concentrations and temperatures. The sensor presents excellent responses toward ammonia and ozone at 300 °C and 200 °C respectively, with good reproducibility, and fast response and recovery time in a wide range of concentrations.

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Keywords: Laser patterning; flexible substrate; gas sensor; ZnO nanoparticles; Kapton.

1. Introduction

Due to the pollution, its negative effects on health and safety industrial requirements, the detection and quantification of hazard gases such as O₃ and NH₃ have been progressed in the field of environmental monitoring, chemical and industrial processes [1]. Flexible substrates have attracted considerable attention due to many advantages as low cost, durability, lightweight, easy and low cost production [2]. Different patterning methods used on rigid substrates have been applied to manufacture flexible substrates, particularly printing process and photolithography [3-4]; however these involve high temperatures, expensive and long production steps.

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This work presents a flexible gas sensor fabricated by direct femtosecond laser patterning. This technique not only reduces production time, but also it is environmentally friendly, representing an excellent and viable alternative instead of chemical and photolithography processes. Femtosecond lasers are particularly suitable tools for micromachining of materials because the energy is concentrated in the material at ultra-short time scale and the process is not affected by heat diffusion effect. This leads to high precision and clean ablation process [5]. The use of femtosecond laser has been reported for film direct laser patterning on flexible substrate in order to produce electronic components [6-7]. With adapted experimental conditions, the film laser ablation can be accomplished with a stress-assisted film ejection process which does not involve any thermal consequences.

2. Experimental

2.1. Materials and sensor fabrication

The flexible gas sensor consists of a 75 μm thin Kapton polyimide foil, with interdigitated electrodes for gas detection, and a Ti/Pt micro-heater device. Kapton polyimide foil was selected as substrate because of its low cost, its high work temperature until 400 $^{\circ}\text{C}$, its excellent thermal stability, its solvent resistance and flexibility. The substrate was treated by oxygen plasma to clean and improve the properties of the surface and the metal film Ti/Pt was deposited by magnetron sputtering with thickness of 5 nm and 100 nm respectively. Finally, the circuit patterns were obtained by femtosecond laser ablation.

The laser source is a femtosecond-diode-pumped ytterbium amplified laser (Amplitudes Systemes S-Pulse HP). The operating wavelength is 1030 nm with 5 nm spectral bandwidth and the pulse duration was set to 350 fs \pm 20fs for the experiments (estimated from single shot autocorrelation trace). The laser power was adjusted externally with a half waveplate and a polarizer. The beam was focused on the sample after passing through a set of galvomirrors and f-theta-lens. Finally, the metal layer ablated was removed from the substrate by a shock wave assisted delamination process. The experimental configuration used is schematized in Fig. 1.

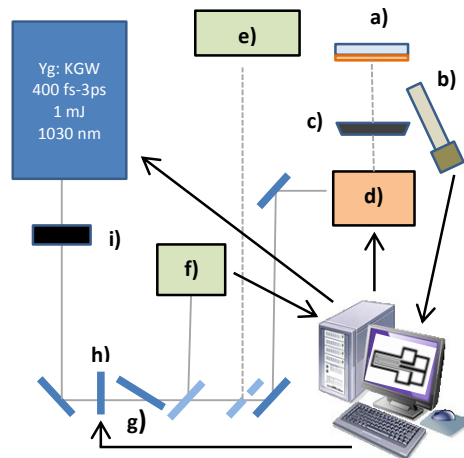


Fig. 1. Experimental configuration used for the experiments: a) Sample, b) Macroscope, c) F-Theta lenses, d) Galvo – mirrors, e) Auto correlator, f) Pyroelectric detector, g) Polarizer, h) Half wave plate, i) Shutter.

The platform was validated by thermal simulation using finite element presenting a homogeneous temperature around the sensible area. An electrical calibration of the heater device has been done in order to know the relation between the temperature and the Pt temperature sensor.

The gas sensing properties were studied using a commercial ink of ZnO nanoparticles as sensible material deposited by drop coating with 280 nm film thickness, and an annealing of 300 °C for 3 hours under environmental conditions has been done in order to improve the film density, the quality and the stability of the sensible material. Fig. 2 presents a flexible gas sensor fabricated by this technique.

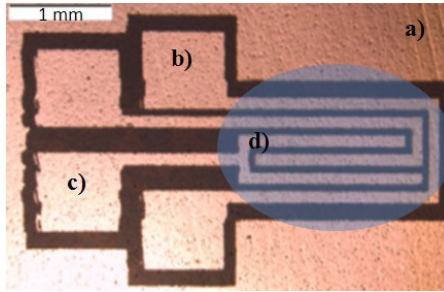


Fig. 2. Flexible sensor fabricated: a) Kapton flexible substrate, b) Microheater, c) Interdigitated electrodes, d) ZnO sensitive material.

3. Result and discussion

The gas sensing properties were studied by measuring the resistance through the sensible material in a close chamber, a programmable power supply to control the temperature and a source meter Keithley 6430. In order to find the best operational conditions, the sample was tested at different temperatures from 25 °C to 350 °C with a target exposure of 1 minute. The best results were found at 200 °C for ozone, and 300 °C for ammonia.

The sample repeatability and the free pollution were studied under different gas concentrations, from 5 ppb to 300 ppb for ozone at 200 °C (Fig. 3), and from 5 ppm to 100 ppm for ammonia at 300 °C (Fig. 4), both from increasing (Up) to decreasing order (Down).

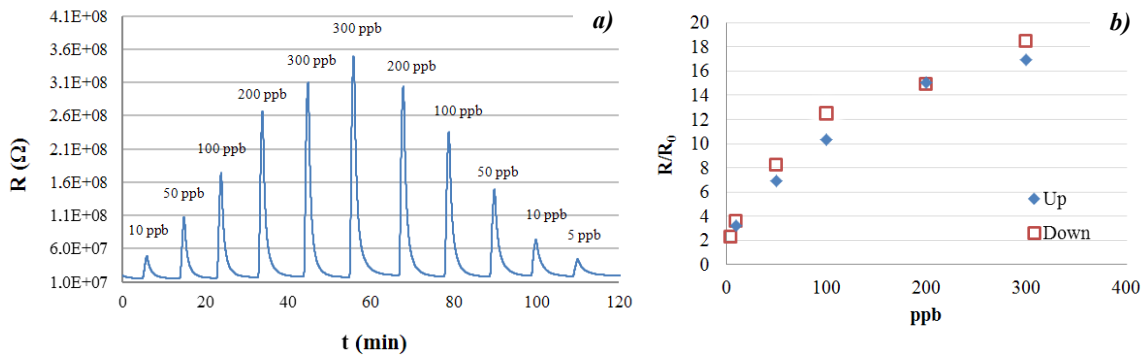


Fig. 3. Sensor response over Ozone at 200°C: a) Range of detection, b) Repeatability

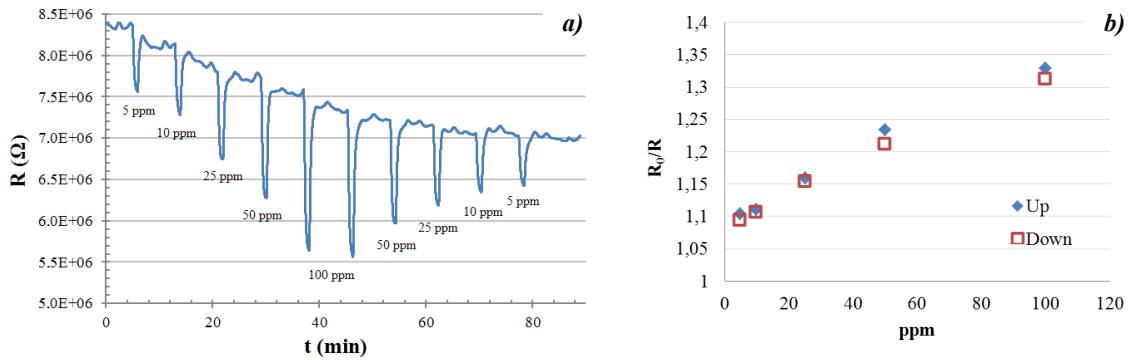


Fig. 4. Sensor response over Ammonia at 300°C: a) Range of detection, b) Repeatability

Although the sample presented small response variations towards ozone and ammonia, the sensor presented excellent response, fast response/recovery time, and very good range of detection for both gases. Also, the good repeatability point out that after several tests, the sensor is free of pollution and the sensitive materials does not present saturation under large gas concentrations.

4. Conclusion

A flexible platform for gas sensor applications was fabricated by direct laser patterning with Ti/Pt interdigitated electrodes. A thermal simulation by finite elements has been done to validate the platform and an electrical calibration of the heater device in order to know the relation between the temperature and the Pt sensor.

The gas sensing properties were investigated using a commercial ink of ZnO nanoparticles with 280 nm film thickness towards ozone and ammonia as representative oxidizing and reducing gases at several concentrations. The samples have presented excellent responses, fast response/recovery times, and very good range of detection, from 5 ppb to 300 ppb for ozone at 200 °C, and from 5 ppm to 100 ppm for ammonia at 300 °C. Direct laser patterning on flexible substrate represents a viable possibility to develop low cost gas sensor avoiding long and expensive productions, high temperatures and chemical steps involved in other fabrication methods.

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