# Investigation of Electrode Patterns Suitable for Nano-Litre Drop Coated Conducting Polymer Composite Sensors

K.I. Arshak, C. Cunniffe, E.G. Moore and L.M. Cavanagh

*Abstract*— **This study presents an analysis of electrode patterns suitable for use with drop coated conducting polymer gas sensors. A thin-film technique was used to efficiently fabricate the copper electrode patterns [1]. Conducting Polymer Composite (CPC) materials were deposited using a 500 nano-litre syringe onto the electrode patterns to produce an array of sensors for organic solvent vapour detection. The sensors were exposed to propanol vapour in steps of 3000 ppm from a minimum concentration of 5000 ppm up to a maximum concentration of 20,000 ppm. Empirical results showed that a non-parallel electrode configuration produces a marginally larger responce and is also less noisy than the interdigitated or parallel electrode configurations. Results show that incresing the baseline resistance of the sensing material gives a larger responce.**

## I. Introduction

Much research has been carried out in the area of electrode geometry for use in gas sensors in the past [2], [3]. Previous works investigated the effect of geometry and position of electrodes for semi-conductor gas sensors [3]. It was discussed in the conclusion that placing electrodes beneath the sensing layer is not the optimal site, but if they are placed as such a wider electrode gap increases sensitivity [3]. It was also observed in a recent work [4] that noise levels decrese as electrode gap distances increase with electrode gaps ranging from 20$\mu$m -140$\mu$m where it was stated that the underlying physics causing this was still being investigated. Previous work on electrode patterns for use with ploymer carbon-black composites was carried out where spray coating was used to deposit the sensing material resulting in a homogenous sensing layer [2]. The electrode patterns investigated included 42 circular configurations. It was shown in that work that the electrode geometry did not have an effect on sensor responce magnitude but noise properties are strongly effected by electrode configuration [2]. It is the aim of this work to investigate the optimal electrode pattern for use beneath a drop coated conducting polymer composite sensing material. The material was deposited using a drop coating technique. Upon deposition of the material drop the conducting polymer composite dispersed to from a ring structure. A number of different patterns (Fig. 2) were investigated to show which patterns yeild noisy responces. Different gap widths in parallel electrode configuration were tested to find a relationship between gap width and baseline resistance. A range of sensor baseline resistances were also used to find correlations between baseline resistance and sensor responce. The sensor arrays were exposed to solvent concentrations of 5000ppm to 20000ppm in increments of 3000ppm.

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## II. Experimental

The sensors were produced on an alumina substrate, which was coated with a layer of copper using an Edwards Thermal Evaporation unit. The resulting substrate was then coated with photo resist using a spin coater. Patterns were designed using Eagle PCB software and printed on acetate. The pattern was UV exposed onto the substrate, and then subsequently dipped in developer and etched. The remaining photoresist was then striped from the pattern on the substrate. A more detailed description of this process is described in [1]. The sensing material composed of carbon black, polyethylene adipate, and surfactant as described earlier [5] and drop coated using a 500 nano litre syringe set to deposit 100 nano litres. The drop coating apparatus is shown in Fig. 1

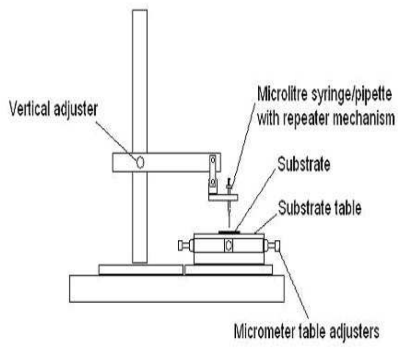


Fig. 1. Setup Used For Drop Coating Sensor Materials.

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The 25.4mm x 12.7mm alumina substrate may be inserted into the testing equipment to enable the patterns to the left of the substrate (Fig. 2) to be tested and then inserted to allow the patterns on the right of the substrate (Fig. 2) to be tested. The sensor arrays were placed in a dynamic flow gas test chamber, which permitted the arrays to be exposed to specific vapour concentrations in a controlled manner. The chamber used a Bronkhorst EL-Flow mass flow meter/controller to control the carrier gas and a $\mu$-Flow liquid mass flow meter with a Controlled Evaporator Mixer (CEM). An EZ-7000 controller unit was used to manually operate the liquid and gas flow controllers. The system was serially connected to a PC for automatic operation. The sensors were exposed to propanol vapour in steps of 3000 ppm from a minimum concentration of 5000 ppm up to a maximum concentration of 20,000 ppm. The exposure cycle consisted of a 30 seconds flush period followed by 60 seconds exposure to the solvent vapour and another 30 seconds flush. The array responses were recorded using a National Instruments data acquisition card (Model No: PCI-MIO-16E-4) and LabVIEW software.

## III. Results And Discussion

Electrode patterns (Fig. 2) were drafted using Cadsoft Eagle PCB design software such that two different configurations may be tested using one drop of sensing material to eliminate sensor-to-sensor reproducibility issues. This allowed for direct comparisons between electrode configurations for each drop of sensing material deposited across each electrode. The electrode configurations consisted of varying gaps between the points and different angles of attack of electrode into the drop of sensing material as well as an interdigitated configuration (Fig. 2). Table I details the electrode gaps at each stage of the manufacturing process and Table II details the baseline resistance of the sensors.

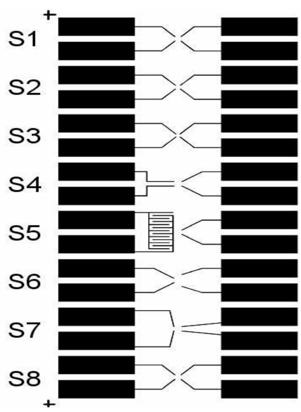


Fig. 2. Electrode pattern allowing for the testing of two electrode patterns.

TABLE I
Electrode Gaps Specification (all figures in $\mu$m)

| Sensor | Process Stage | Left | Right |
|---|---|---|---|
| | CAD Output | 200 | 200 |
| S1 | Mask | 97.9 | 116.6 |
| S1 | Etched Pattern | 102.6 | 166.6 |
| | CAD Output | 150 | 150 |
| S2 | Mask | 0 | 0 |
| S2 | Etched Pattern | 0 | 0 |
| | CAD Output | 100 | 100 |
| S3 | Mask | 0 | 0 |
| S3 | Etched Pattern | 0 | 0 |
| | CAD Output | 200 | 200 |
| S4 | Mask | 121.2 | 116.6 |
| S4 | Etched Pattern | 107.2 | 135.2 |
| | CAD Output | 200 | 200 |
| S5 | Mask | ~107 | 111.9 |
| S5 | Etched Pattern | ~121 | 121.2 |
| | CAD Output | 200 | 700 |
| S6 | Mask | 135.3 | 587.4 |
| S6 | Etched Pattern | 139.9 | 596.7 |
| | CAD Output | 200 | 200 |
| S7 | Mask | 172.6 | 103.4 |
| S7 | Etched Pattern | 158.5 | 111.9 |
| | CAD Output | 200 | 200 |
| S8 | Mask | 103 | 107.3 |
| S8 | Etched Pattern | 93.24 | 95 |

These configurations presented a method of determining the important features of the dropped sensing material. A stereomicroscope image of the acetate mask focused on S4 is presented in Fig. 3, and the etched pattern of S4 is displayed in Fig. 4.

A volume of 100 nano-litres of Polyethylene adipate\carbon black composite material was deposited onto the electrodes using a nano-litre drop coating technique. Fig. 5 shows a stereomicroscope image of the resulting sensor with the deposited material focusing on S4. The image shows the electrodes beneath the material in both a parallel and non parallel configuration. The ring structure which is formed on deposition and is the most significant constituent element of the material is also visable in Fig. 5.

By varying the structure of the electrode patterns the resultant data showed that the most important structure of the sensing material is the ring structure around the edge of the dropped material. The electrode gap in the middle of the sensing material had little effect whereas the distance between the electrodes where the ring crossed over the electrode defined the baseline resistance of the sensor. Sensors with a higher baseline resistance boasted a larger and less noisy response while the sensors with electrodes, which lay parallel to each other,

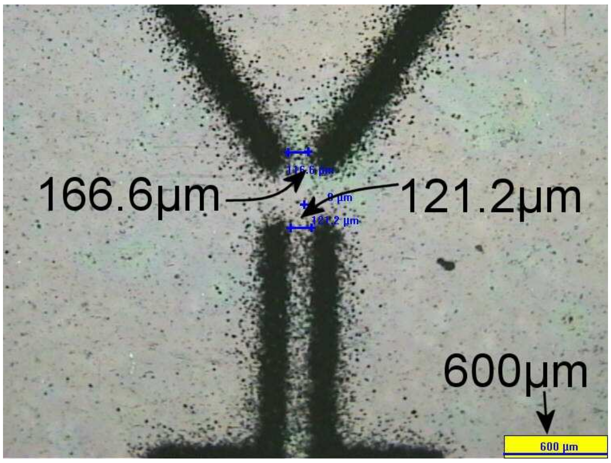


Fig. 3. Stereomicroscope image focusing on S4 of mask printed on acetate.

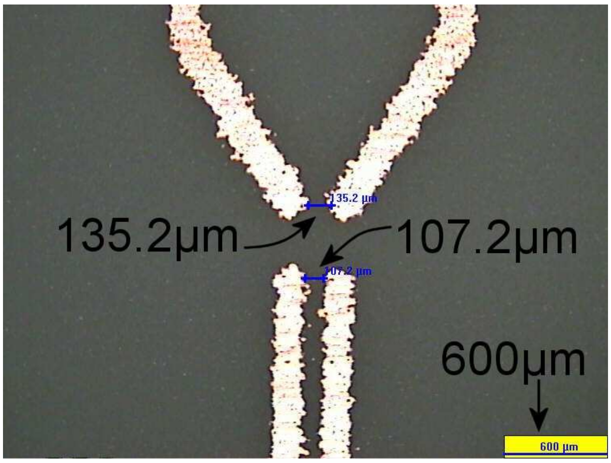


Fig. 4. Stereomicroscope image focusing on S4 of etched pattern.

produced noisy response such as the patterns S4 and S5 in Fig. 2. The sensor responses were pre-processed using fractional baseline manipulation, shown in Equation. (1) which produces a normalised response and can enhance contrast and reduce drift effects [6].

$$V = \frac{V_{gas} - V_{air}}{V_{air}} \quad (1)$$

Where $V_{gas}$ is the voltage drop across the sensor in responce to the vapourised solvent and $V_{air}$ is the voltage drop across the sensor in responce to the flush gas.

A typical response for sensor pattern S4 is displayed in Fig. 6 showing that the parallel electrodes produces a noisy response and the alternative pattern on the right hand side of S4 yielded a cleaner response and also exhibited a marginally larger response. Fig. 7 shows a typical responce from an interdigitated electrode pattern.

To test the effect of electrode gap width in a parallel configuration an array was designed with increasing gap sizes from 200$\mu$m to 800 $\mu$m. The maximum $\triangle V/V\%$ was extracted from the raw data. Fig. 8 shows the resulting graph of baseline resistance versus percentage change of voltage the seven parallel electrode configurations with varying gaps. The $\Delta V/V\%$ vs $R_0$ graph shows a trend in the data illustrating that the percentage voltage change increases as the baseline resistance increases, however the electrode Gap vs $R_0$ graph also shows there was no correlation between the baseline resistance of the sensor and the electrode gap width. Employing interdigitated electrodes for this applications didn't enhance the sensor responce. Due to the parallel nature of the interdigitated fingers the sensor exhibited a similar but more exaggerated noisy responce illustrated in Fig. 7 to that of the parallel electrodes. The interdigitated configuration contribute to lowering the baseline resistance but as shown in Fig. 8 a higher baseline resistance yields a better percentage voltage change.

TABLE II

Baseline Resistances of Sensors (all figures in kΩ)

| Sensor | Baseline Resistance | |
|---|---|---|
| | Left | Right |
| S1 | 145.5 | 186.5 |
| S2 | 0 | 0 |
| S3 | 0 | 0 |
| S4 | 29 | 34.75 |
| S5 | 20 | 138 |
| S6 | 48.2 | 64 |
| S7 | 75.5 | 31.56 |
| S8 | 69.45 | 59.3 |

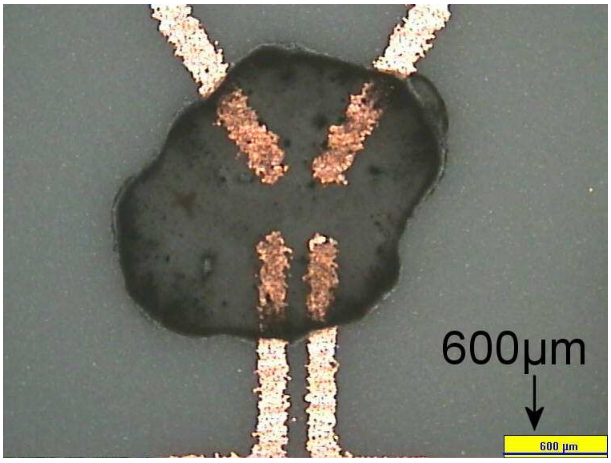


Fig. 5. Stereomicroscope image focusing on S4 of etched pattern with deposited material showing ring structure.

## IV. Conclusion

Results show that incresing the baseline resistance of the sensing material gives a larger responce and there is

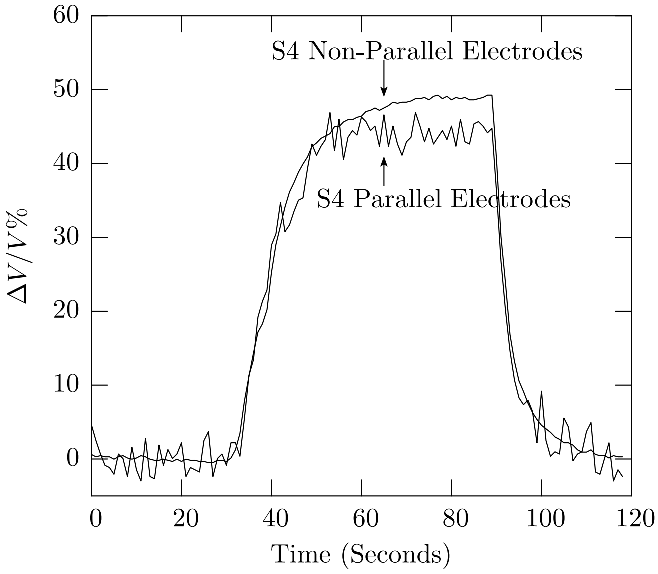


Fig. 6. Graph showing the typical response of PEA sensors response to 20000ppm of Propanol using electrode pattern S4.

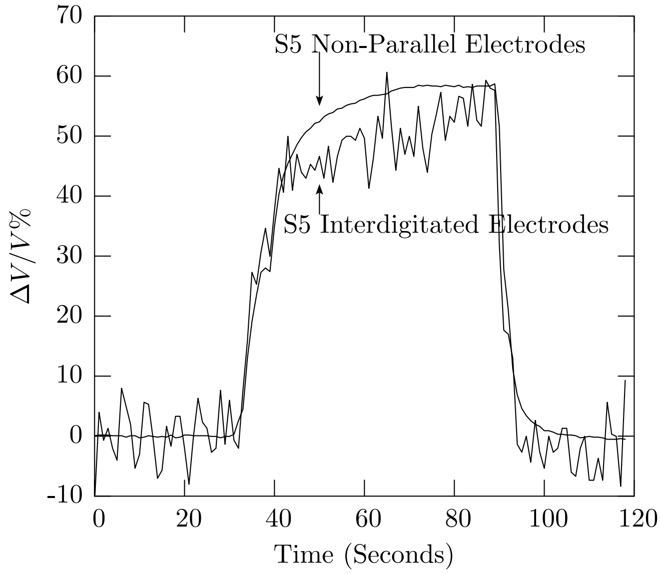


Fig. 7. Graph showing the typical response of PEA sensors response to 20000ppm of Propanol using electrode pattern S5.

no correlation between the baseline resistance and the electrode gap in a parallel configuration. Empirical results showed that a non-parallel electrode configuration produces a marginally larger responce and is also less noisy than the interdigitated or parallel electrode configurations. The electrode gaps are less important due to the material deposition method as the principle components of the material disperse to the edges to form a ring structure which governs the base line resistance. This work shows that manipulating the electrode pattern can improve the sensitivity and stability of these drop coated conducting polymer composite sensors for use in electronic nose applications.

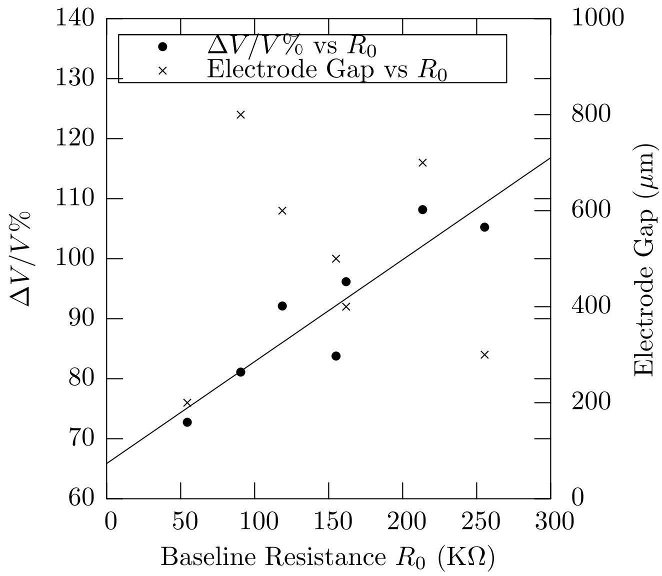


Fig. 8. Plot of Baseline Resistance vs Change in Voltage and Electrode Gap for Seven Parallel Plate Electrodes


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