Colorimetric Sensor Array based on Ink-jet Printing Method for Gas Detection System

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***Abstract*—Hazardous gas detection is one of the important issues in the industry dealing with the toxic chemicals. The colorimetric sensor array has been developed for detection of the Toxic Industrial Chemicals (TICs). This study describes a colorimetric sensor array by using printing method and Complementary Metal Oxide Semiconductor (CMOS) image sensor for highly sensitive gas detection system. The sensor array is produced by the piezo inkjet-printer in order to achieve array uniformity, cost efficiency and ability to adjust the array thickness. The initial colors of sensor array are changed by chemical gases within 10 seconds of exposure to Time Weighted Average (TWA) concentration. Detection of the color change was performed before and after a gas exposure. This printing method of sensor array demonstrates the potential for sensing application of sensitivity, rapidity and it is a simple method to use.**

Keywords - *Hazardous Gas sensing, Inkjet printing, CMOS Image sensor, Colorimetric sensor.*

I. INTRODUCTION

Gas detection system is the most important one in industries and recently colorimetric array of gas detection is identified as the dominant method of application. Usually, chemical and pH indicators are applied to configure the array. But the array composed of a variety of dyes in a tool can selectively determine the hazardous gas. A colorimetric method of detecting a hazardous gas by color change has the advantage of low cost, simplicity and can be made as a portable device [1]. The printing method of making array is an effective way to create the array spot on gas detection chip and to create an accurately depositing spot with a small amount of dye on the surface of a wide range of substrate. Piezo inkjet technology is a versatile tool for various fabrication processes of the substrate [2] and has advantages of no risk of substrate damage, low cost and ease for parallel mass production. Furthermore, printing method can take place as an alternative method to the application of analytical chemistry, biological sample array and the various fabrication areas. Chip array is analyzed by the CMOS image sensor and various chemical indicators for specific detection of toxic gases are used to make the sensor array. That array shows the colors that composed of red, green and blue (RGB) and the CMOS image sensor can absorb RGB value. The RGB value can be converted to various color spaces that allow for quantification of color change of the gas concentration on the linear relationship of the component consisting of various color spaces. The hazardous gas detection system for performing chip fabrication with printing method, detection using CMOS image sensor and analysis can provide great application for gas sensors in the industry.

II. EXPERIMENTAL

A. Inkjet-printed sensor arrays

An Epson Stylus T10 is used as an inkjet printer. All array spots are fabricated by printing method on the polyethylene terephthalate (PET) film with four types of chemicals or pH indicator dyes which are Methyl Red (MR), Nitrazine Yellow (NY), Bromo Phenol Blue (BPB), and Bromo Cresol Green (BCG). Printing of dyes prepared to use water and ethanol based solvent for inkjet-print. Dissolved dyes were filtered by syringe filter with 0.1 ㎛ pore size of PVDF membrane. Each array is printed as spots of 2.4mm diameter with 800nm thickness and then dried at room temperature for 3 days to make them stable of initial color of the array.

B. CMOS image sensor

A CMOS image sensor is a device that can absorb photons which constitute a color or image. CMOS image sensor converts the color to a digital value of RGB by using analog to digital converter (ADC). The experiment was carried out using CMOS image sensor that contains 376 x

314 pixel array of 10 bit ADC [3]. Color detection based on the CMOS image sensor was performed before and after gas exposure. The overall test scheme is shown in Fig. 1.

C. Gas exposure test

Hydrochloric acid and ammonia gas were used in this experiment and the standard of exposure limits is given as the TWA concentration of each gas. TWA concentration of hydrochloric acid was 5ppm and that of ammonia was 20ppm. The gas concentrations of the exposure test were allowable to the level of TWA. Each of the gases used in this study was prepared in 1 liter hermetic chamber and vaporized from liquid phase of chemical at 60°C. After complete vaporization, a gas was exposed to the array chips for 10 seconds.

D. Data processing and converting of color space

The color value of RGB was measured by CMOS image sensor after the exposure and compared with the initial color. The average color value of 120 pixels in the center of a 2.4mm spot is converted into a digital RGB value. RGB value is directly converted using CIELAB-CIEXYZ conversions which allow all components of that color space to have full 8-bit range of RGB.

III. RESULT

The sensor arrays produced by printing method were exposed to ammonia and hydrochloric acid gases at three different concentrations (ammonia; 5ppm, 10ppm, and 20ppm, hydrochloric acid; 1.25ppm, 2.5ppm, and 5ppm). The color changes of an array under hydrochloric acid show a significant change in MR and NY spots whereas BPB and BCG spots are more sensitive to ammonia gas as shown in Fig 2. The color changes were detected using CMOS image sensor after gas exposure and RGB value were directly converted to the CIE-Lab color space to calculate the color differentiation value, as shown in Fig. 3. The color differentiation values depend on the concentration of each gas. Fig. 4 shows the luminance values of BCG and BPB. Luminance values are gradually reduced as the concentration of ammonia gas increases. This suggests that it is possible to quantify the gas concentration based on the color change comparison. The uniform spot array of chemical indicator is manageable by using printing method. It is possible to quantify a gas concentration by optimizing dye array state, including uniformity, a suitable concentration condition, and the thickness.

IV. CONCLUSION

Various industries, factories, and laboratories are amongst the major places requiring the use of toxic gases that may lead to serious problems if released, and can be dangerous to human life. We have carried out a series of trials to standardize the colorimetric toxic gas detection system. In addition, further studies are underway regarding the use of the same technology to detect 10 toxic gases and to test the detection system under various conditions. We believe that the toxic gas detection system will be a suitable and sensitive device.

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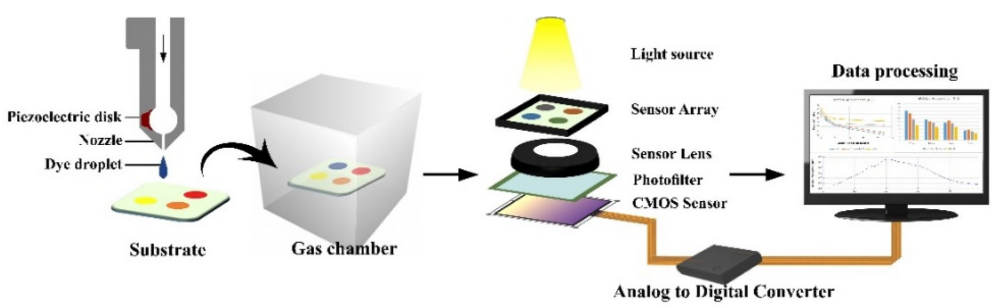

Figure 1. Gas detection system based on the piezo inkjet printing method.

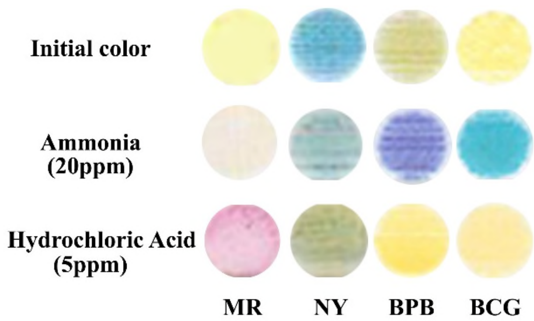

Figure 2. The colorimetric sensor array and color difference of dyes.

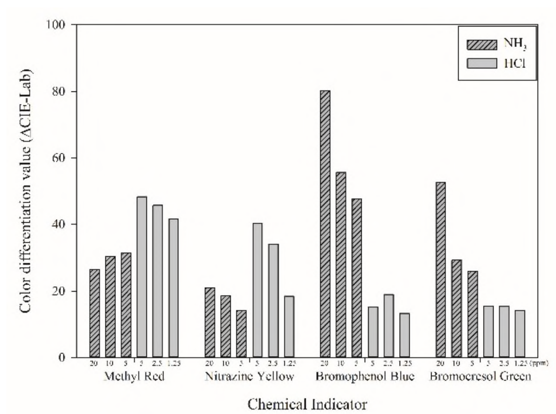

Figure 3. Color differentiation value of CIE-Lab color space.

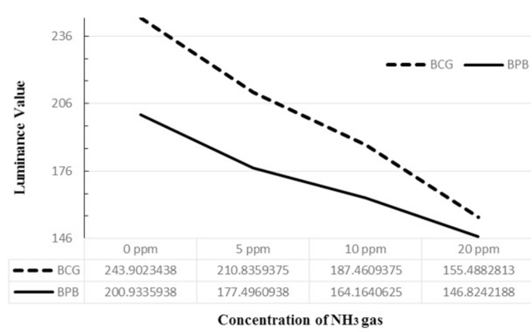

Figure 4. Luminance value gradient of BCG and BPB at ammonia gas.