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Abstract

論文内容の要旨　(博士)

Title of Thesis 博士学位論文名	Smart Ultraviolet Sensor for Hydrogen Flame Detector Application based on Neuro-OEIC and FPGA ニューロ OEIC と FPGA 技術を基にした水素火炎検知用スマート紫外光センサ

(Approx. 800 words)

(要旨　1,200 字程度)

It is important to have a continuous monitoring system for detecting a hydrogen flame in industries, laboratories, or residential area to prevent further damages. Detecting a hydrogen flame in daylight at a wide observation area is difficult since the hydrogen flame produces a pale blue color and generates less heat, but emits UV-C radiation. By exploiting the application of the optoelectronic integrated circuits (OEIC), a smart UV sensor for detecting a hydrogen flame is proposed. This doctoral thesis presents a study on a smart UV sensor for hydrogen flame detector application by three-dimensional (3-D) integration between a neuro-OEIC and an FPGA to realize a chip with small form factor and low-power consumption.

The smart UV sensor not only detects the hydrogen flame but also delivers the information about the location, speed, direction, and spreading status of the hydrogen flame. The smart UV sensor contains of three parts: focal plane array (FPA) of UV-sensitive photodiodes, complementary metal oxide semiconductor (CMOS) circuit as a readout circuit and an edge detection circuit (EDC), and the motion object detection circuit implemented in the field-programmable gate array (FPGA). The neuro-OEIC that mimics the outer vertebrate retina combines the FPA and EDC to extract the edge of the detected object for acting as a preprocessing unit. While the FPGA is used as an image analyzer.

Previous research in our laboratory fabricated a backside-illuminated Schottky barrier diode $Pt/n^{-}-Al_{0.49}Ga_{0.51}N$ on sapphire as the UV focal plane array. The photodiode has a size of 250 μm x 250 μm with a pitch of 500 μm. The leakage current was 10^{-13}A at -3.0 V bias with an ideal factor of 1.14. Under illumination, the photodiode showed a photocurrent of 8 x 10^{-11} A with the responsivity of 2 x 10^{-4} A/W at a radiation power of 6.4 μW/mm^2. This reveals that the external quantum efficiency of the fabricated photodiode was ~0.1%. In near future, the external quantum efficiency of the photodiode will be expected increasing up to 10%. Thus, the photodiode will produce photocurrent in a range of 14.1 fA - 14.1 nA.

The motion object detection circuit in the FPGA utilized histogram projection to determine the object's position within the image. The image is projected vertically and horizontally. Both edges of the projected object are located to get the size of the object. From those edges, other

information is derived such as the centroid, speed, direction, and spreading status of the object. A two-dimensional array of 250 x 250 pixels was simulated to evaluate the system's calculation of the speed and direction of the given object. The execution time of the implemented circuit in the Spartan-6 XC6SLX25 FPGA device was 0.05 ms. Thus, the implemented circuit in the FPGA might process the images up to 20,000 frames/s.

The hydrogen flame was targeted to occur as a spurt with a height of 5 m with a flame speed of 100 m/s at 10 m away from the sensor. An optical subsystem such as a convex lens with a focal length of 3 mm might be added to have a better focused object as well as increasing the photon flux received by the focal plane array. Using the fabricated focal plane array, the minimum number of the pixel required to detect the targeted hydrogen flame is 3 x 3 pixels. In this stage, the CMOS circuit was fabricated and wired-integrated with the motion object detection circuit implemented in the FPGA to evaluate the calculation of the object's flame speed. The photocurrents were simulated using a microcontroller that was programmed to generate moving patterns. The one-dimensional array CMOS circuit of 1 x 16 pixels was fabricated with 1.5 μm process technology using 5 micron lambda rules. The silicon diode as the readout circuit has a size of 50 μm x 50 μm with a forward voltage of 0.58 V and a leakage current of 0.64 nA at -1.0 V bias. The MOS transistor has a width and a length of 15 μm and 10 μm, respectively. The NMOS has a threshold voltage of 1.6 V with a saturation current of 0.3 mA at a V_{GS} of 5.0 V and a V_{DS} of 3.0 V. The PMOS has a threshold voltage of -1.6 V with a saturation current of -0.13 mA at a V_{GS} of -5.0 V and a V_{DS} of -3.0 V. The fabricated EDC chip can detect the given photocurrent in a range of 100 nA - 50 μA with V_{DD} of 5 V, V_{OFS} of 2.2 V, and V_{TH} of 2.2 V. The wired-integrated system was evaluated to calculate the object with a speed in range of 0.86 – 1,957.8 pixels/s which is equal to an actual flame speed of 1.43 - 3,263 m/s.