Electrically Programmable Analog Device As An Ultraviolet Light Sensor

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***Abstract*—Electrically Programmable Analog Device (EPAD) is a commercial semiconductor device based on a floating gate MOS transistor. It is possible to charge the EPADs floating gate with electrons and thus increase the threshold voltage of the MOS transistor. Decapsulation of the ALD1108E integrated circuit containing four EPADs was performed to expose the semiconductor structure to ultraviolet light. By irradiating with different UV light sources, the threshold voltage of an EPAD with a pre-charged floating gate decreases, indicating a possibility for UV radiation detection. The sensitivity of EPAD to the UV light range of 311 to 400 nm was investigated. The floating gate MOS transistor (EPAD), which has a more charged floating gate with electrons, i.e. higher threshold voltage value, shows higher sensitivity compared to EPAD with a lower charged floating gate, i.e. lower threshold voltage value.**

***Index Terms*—Floating gate MOS transistor, Ultraviolet Light, Light Sensor, EPAD, IC decapsulation**

I. Introduction

MEMORIES that remember content even after a power failure are called Non-Volatile Memories. First came the Mask ROM (Read Only Memory) memory, i.e. mask programmed ROM. A whole array of memory cells is formed on the chip in the form of a matrix. Then, according to the user's request, a mask for the photolithographic procedure is created, which defines the openings for drawing the lines of connection between cells and the power supply. Cells that should contain a logic "1" are connected to the power supply (highly doped polysilicon is applied through the opening on the mask to make contact), while cells that should contain a logic "0" remain unbound to the power supply. The Mask ROM stores data permanently, the process is very expensive, and every change requires a change of the photolithography mask.

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In order to solve the problem of expensive production, PROM (Programmable ROM) memory is created; here, the data is stored by the user himself with specialized electrical devices. Namely, PROM is produced so that all cells have a logic "1", and they are all connected to the power supply. The interruption of connection lines between individual cells is done by passing a high-density current, which melts the desired line. Once programmed, the PROM cannot be reprogrammed.

The next memory that emerged with technology development is an EPROM (Erasable & Programmable ROM). For the first time, it is possible to delete data, which is done by exposing the memory to UV rays. EPROM is the first memory to have a floating gate (FG) in its structure, and thanks to such a device, it is possible to erase the charge on the pre-charged floating gate and thus change the threshold voltage of the MOS transistor. Decreasing the threshold voltage leads to a change in the logical state of the cell from "0" to "1". The memory is byte-addressable when writing and reading, while the deletion process covers the entire memory. When deleting, the memory chip must be removed from the motherboard and exposed to UV radiation for 20 minutes [1]. The complete deletion process needs to be done even though only one byte needs to be changed.

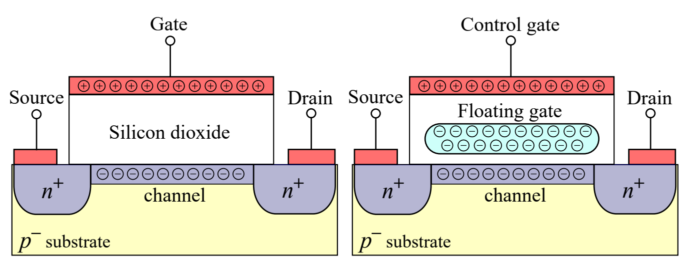

Fig. 1. Left: Cross-section of a MOS transistor. Right: Cross-section of a MOS transistor with a floating gate

Figure 1 shows the structure of a MOS transistor, and the structure of a MOS transistor with a floating gate (FG). During ultraviolet radiation, photons reach the floating gate and generate electron-hole pairs in the vicinity of the floating gate. Due to the electric field that originates from the floating gate, the generated carriers are separated because it is charged with electrons. The holes recombine with the electrons located on the floating gate, and thus the amount of charge is reduced, which leads to a lower threshold voltage value of the MOS transistor.

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II. Materials and Experimental Setup

The experiment consisted of irradiating the decapsulated IC ALD1108E [2] with three different types of UV sources. Decapsulation of the ALD1108E integrated circuit is a high-tech process that requires the removal of plastic above the chip so that light can reach the semiconductor device, while the bonds connecting the chip to the package must not be damaged. This process was performed at the Tyndall National Institute, Cork, Ireland. Since decapsulated integrated circuits are extremely sensitive to handling and potential mechanical damage and chip contamination if handled in dirty conditions, the experiment was performed in a cleanroom at the Center of Microelectronic Technologies, Institute of Chemistry, Technology and Metallurgy, Serbia. The number of particles in a cleanroom was controlled using a PCE-PCO 1 particle counter. During the experiment, all measured particle sizes were filtered to zero. The measurement of particles was done in 21 seconds, which corresponds to airflow of 1 litre.

In order to protect the decapsulated chip from mechanical damage during the handling and measurements, special housing for UV experiments made of polylactic acid (PLA) material with a quartz window was designed, as shown in Figure 2.

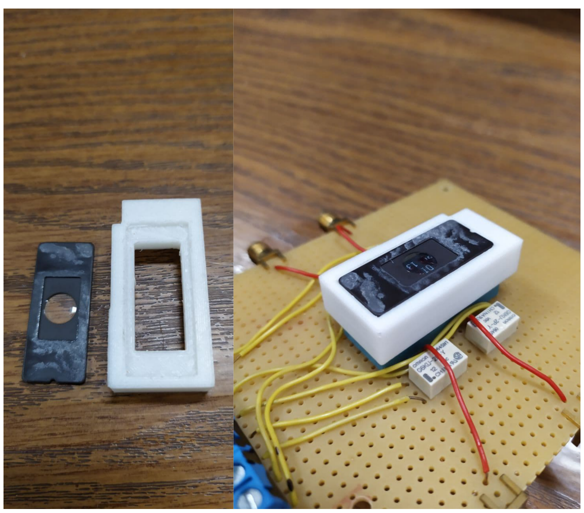

Fig. 2. Left: A quartz window and housing for decapsulated IC made of PLA material. Right: Assembled housing on the IC ALD1108E inserted in the ZIF socket.

The housing was designed in the Solid Edge 2021 Academic version and then fabricated using the Creality Ender 6 Core-XY 3D printer. The decapsulated integrated circuit has a weakened plastic housing and therefore needs to be handled very carefully, especially when inserted into the IC socket. Therefore, an electric circuit for measuring the characteristics of EPAD on the IC ALD1108E with a zero insertion force (ZIF) socket has been designed.

The housing is designed to protect the decapsulated IC from all sides but not to touch the plastic DIP of the integrated circuit due to potential damage to the bonds during handling. Therefore the housing is mounted on the ZIF socket in which the integrated circuit is inserted.

Since it is necessary for UV light to penetrate the housing, a quartz window has been installed to enable this. Old EPROM memories had a quartz window on their package so that UV light could erase the memory, and this gave the idea to the authors to use a quartz window from an old memory from ST Microelectronics.

To ensure that a sufficient amount of UV light passes through the selected quartz window, the transmission of our housing was measured using a UV-Visible Spectrophotometer Evolution 60 from Thermo Scientific, and shown in Figure 3.

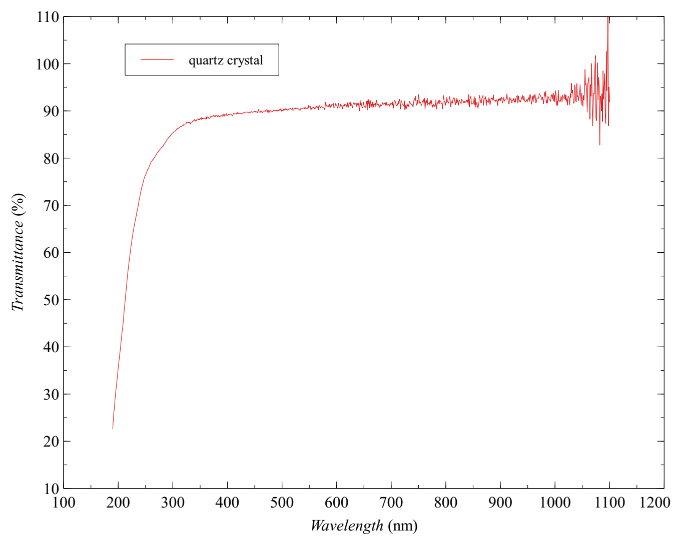

Fig. 3. Transmittance of quartz window mounted in housing made of PLA material.

For a wavelength value of 300 nm, the transmittance is 85% and then increases to 90% for the visible part of the spectrum. The wavelength range for this research is from 300 to 400 nm. The UV light sources used for the purposes of this experiment are: a UV lamp with a 311 nm peak, a UV lamp with a 365 nm peak and a UV LED with a 400 nm peak; their spectrographs are shown in Figures 4 to 6, respectively.

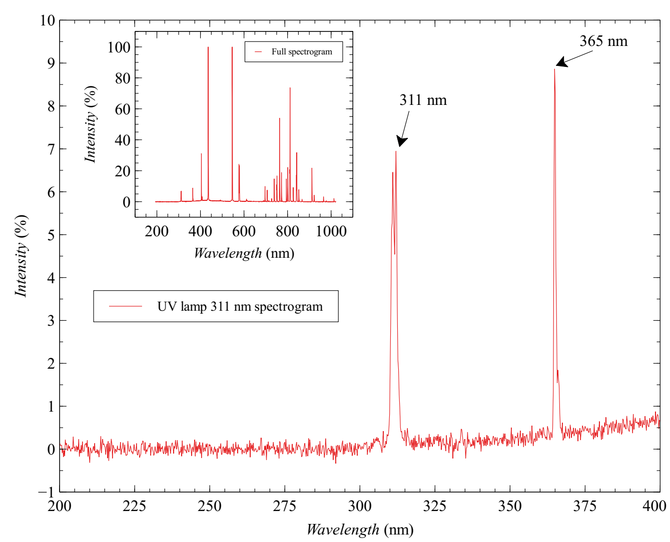

Fig. 4. Spectrogram of UV lamp with 311 nm peak.

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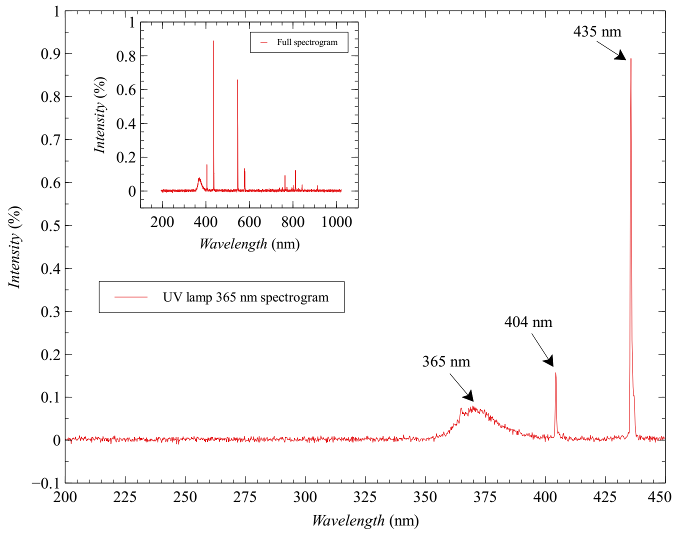

Fig. 5. Spectrogram of UV lamp with 365 nm peak.

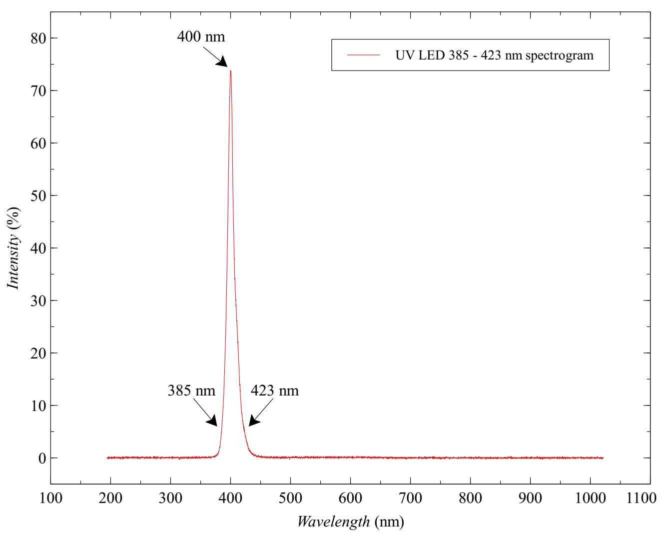

Fig. 6. Spectrogram of UV LED with 400 nm peak.

A UV lamp that emits light with a peak at 311 nm is used for the phototherapeutic treatment of skin diseases by producing vitamin D. As can be seen in Figure 4, this lamp has two peaks in the ultraviolet part of the spectrum at 311 nm and then at 365 nm. Other emitted light is in the visible part of the spectrum.

The following UV lamp used in the experiment has an application as a gel nail dryer. This lamp has only one broad peak in the ultraviolet part of the spectrum at 365 nm, while the others are in the visible part of the spectrum, as can be seen in Figure 5.

The third UV source used in this experiment is a matrix of UV LEDs. The spectrum of this source is clear, unlike UV lamps and has only one peak at 400 nm, at the border of UV and visible light.

III. Results

During the irradiation of the ALD1108E chip, the drift of two floating gate MOS transistors (EPADs) was measured using a Keithley 2636A source measure unit connected to a computer. Drift is monitored at one point of the current-voltage characteristic called the zero temperature coefficient (ZTC) point [3]. Monitoring the change in the drift at this point cancels the influence of temperature on the measurements, which is an essential factor.

ZTC voltage drifts before, during and after UV irradiation for two EPADs with the same value of threshold voltage (initial Vth = 4 V) is shown in Figure 7.

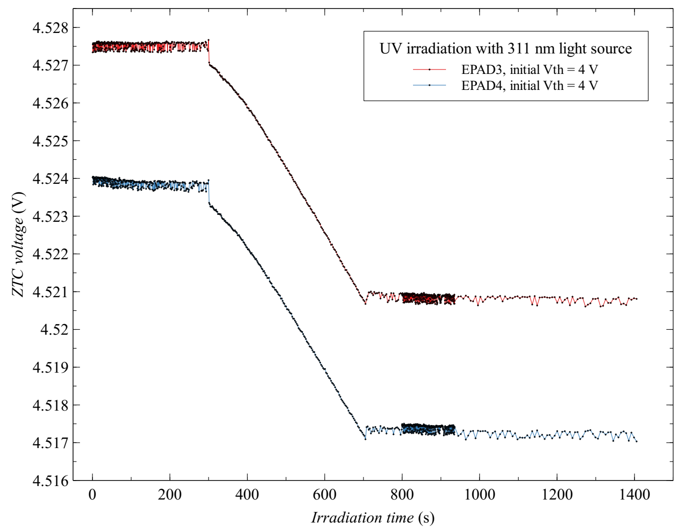

Fig. 7. ZTC voltage drift of EPAD3 and EPAD4 before, during and after UV irradiation of 311 nm light source.

Based on the ZTC point, it is possible to calculate the threshold voltage of the MOS transistor and thus indirectly monitor the threshold voltage but without the influence of temperature because for a fixed temperature (e.g. 25 °), the difference between the threshold voltage value and the ZTC point voltage value is constant. Figure 8 shows the threshold voltage shift during irradiation of two EPADs with a UV lamp of 311 nm peak.

The figure 8 shows EPADs that during the first irradiation had an initial threshold voltage of Vth = 3 V, and during the second irradiation, under the same conditions, EPADs had a threshold voltage of Vth = 4 V. It can be noticed that EPADs have higher sensitivity with higher threshold voltage means with a larger amount of electrons on the floating gate, which can be compared as an analogy to gamma radiation [4]. Also, it is possible to recharge the EPADs floating gate without degradation of its dosimetric characteristics [5].

Figure 9 shows the EPAD threshold voltage shift with the initial threshold voltage value Vth = 4 V.

The weakest response of the EPAD was observed for the UV LED light source, where the threshold voltage shift values are shown in Figure 10.

A linear dependence during irradiation can be observed for all types of UV radiation sources. The same behaviour of this sensor at small threshold voltage shifts was observed

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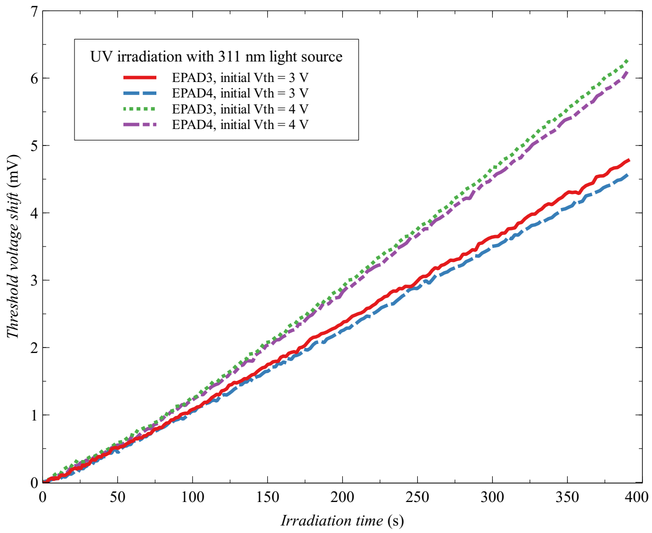

Fig. 8. Threshold voltage shift of EPAD3 and EPAD4 during irradiation of 311 nm light source with different charge on the floating gate.

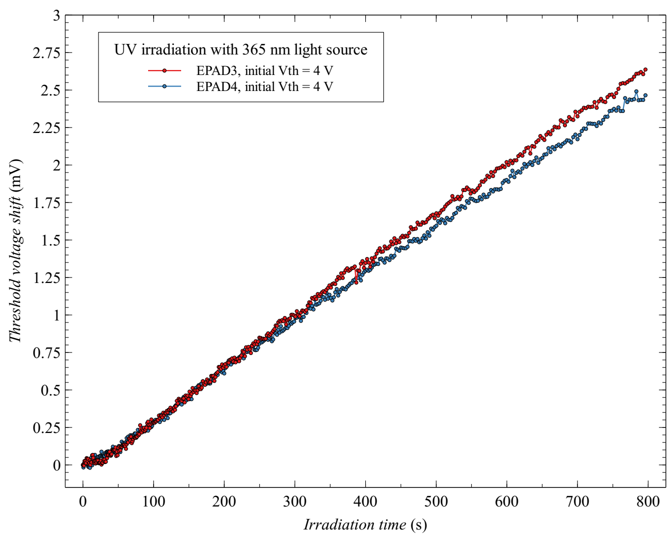

Fig. 9. Threshold voltage shift of EPAD3 and EPAD4 during irradiation of 365 nm light source.

for gamma radiation [4]. These results indicate that it is possible to record UV irradiation with the presented floating gate structure.

IV. Discussion

By analyzing the spectrum of the UV lamp 311 nm in Figure 4 and the spectrum of the UV lamp 365 nm in Figure 5, we can see that both have a peak at 365 nm, which may indicate the possibility that the Vth shift from the first lamp with a peak at 311 nm (presented in Figure 8) originates from the peak at 365 nm. However, the nature of the floating gate device is that the electrons in the floating gate need to receive the minimum energy to surmount the energy barrier (similar to the photoelectric effect), and all photons with minimum or higher energy can decrease the charge on the floating gate and thus reduce the threshold voltage of the transistor

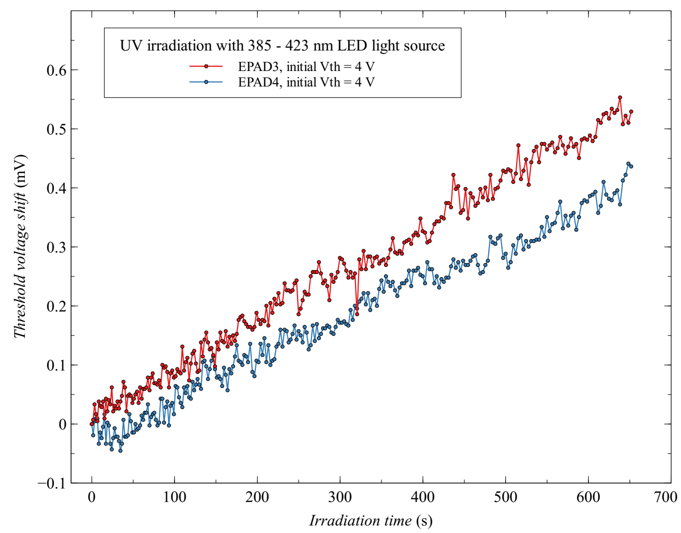

Fig. 10. Threshold voltage shift of EPAD3 and EPAD4 during irradiation of UV LED source.

[6]. This means that all photons with a smaller wavelength of 400 nm (higher energy than 3.09 eV) can decrease the threshold voltage. It is necessary to examine the photon energy limit value of this FG dosimeter in the future.

The UV sensor enables the detection of dangerous wavelengths for human health. The floating gate MOS transistor has good properties as an ionizing radiation dosimeter, so it is possible to use the same component for ultraviolet radiation dosimetry. However, it is necessary to provide a special housing with the quartz window in which the integrated circuit is mounted.

V. Conclusion

The paper presents the possibility of using a floating gate MOS transistor as an ultraviolet sensor. The EPAD has been shown to respond to an ultraviolet radiation range of 311 to 400 nm. A sensor with a floating gate charged with a larger amount of electrons shows higher sensitivity. This component shows promising possibilities for dosimetry of UV radiation for medical purposes such as monitoring the received dose of patients during phototherapy.

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