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Discharging-Phototransistor-Integrated High-Voltage Si Photovoltaic Cells for Fast Driving of an Electrostatic MEMS Actuator by Wavelength Modulation

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Abstract

In this article, we propose a high-voltage PV cell array integrating discharging phototransistors for fast driving of an electrostatic MEMS actuator by light with wavelength modulation. A PV cell array and phototransistors are connected in parallel and colored with green and red lacquer respectively. This circuit repeats charge and discharge of a MEMS actuator if it is irradiated with light whose color periodically changes between red and green. We have conducted measurements and showed that this circuit is effective to drive a MEMS actuator.

1. Introduction

An autonomous distributed microdevice integrating MEMS devices and photovoltaic (PV) cells controlled by light has attractive applications such as a microrobot in a sealed environment and wearable devices. Among MEMS devices, an electrostatic MEMS actuator has various uses and it is desired to be driven dynamically with PV cells on the same chip. However, because an electrostatic MEMS actuator generally requires high voltage (e.g. 100 V), PV cells must generate such a high voltage. The authors' group has previously proposed an on-chip high-voltage silicon PV cell array [1]. This technology is based on standard CMOS technologies, thus ensuring high reliability and quality of the PV cells.

In [2], the authors' group has demonstrated controlling an electrostatic MEMS actuator by light with the high-voltage silicon PV cell array. However, the PV cell array can only charge up the actuator; it took very long time (in the order of minutes) for discharge. It is, therefore, evident that a PV cell array must integrate a discharge circuit for a fast operation of the MEMS actuator. One possible method of discharge is a photodiode connected to a PV cell array in parallel. If light does not come into a PV cell array and comes into a photodiode, this circuit can discharge an electrostatic actuator. This method enables driving of an electrostatic MEMS actuator with light, but the issue is how to select the cell where light hits. In addition, the circuit is desired to be as small as possible.

In this article, we propose a PV cell array with a discharging phototransistor for fast driving of an electrostatic MEMS actuator. It uses wavelength modulation to alter charge and discharge modes and the area of the circuit is smaller than that of the circuit using a photodiode.

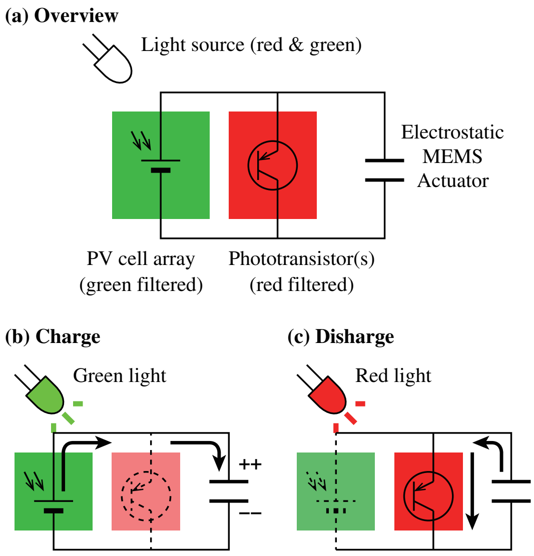

Fig. 1 The proposed PV cell array with phototransistors for discharge to drive an electrostatic MEMS actuator. The charge mode and the discharge mode are realized with wavelength modulation of light.

2. Proposal Method

Fig. 1 is the proposed PV cell array with a discharge circuit. In the circuit, PV cell array and phototransistors are connected to an electrostatic MEMS actuator in parallel. On the PV cell array and the phototransistors are green and red filters respectively. In the charge mode, the circuit is illuminated with green light. Green light comes into the PV cell array and it generates electricity. On the other hand, green light does not come into the red-filtered phototransistors and thus it does not let the current flow. In the discharge mode, the circuit is illuminated with red light. In this mode, the green-filtered PV cell array does not work and the red-filtered phototransistors let current flow through it, which discharges the actuator.

This discharge circuit has an advantage in compactness. It is smaller than the circuit using photodiodes instead of phototransistors. One reason is that, under the same intensity of light, the current which a phototransistor allows to flow is h_{FE} times larger than the one which a photodiode allows, where h_{FE} is an amplification factor of a phototransistor. It means the area of phototransistors can be $1/h_{FE}$ of the area of a photodiode. The other reason is that a phototransistor has high breakdown voltage and thus the required number of photo-

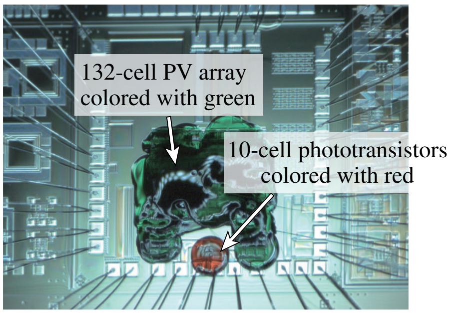

Fig. 2 The photograph of a chip with the proposed circuit. In the photograph a 132-cell PV cell array and 10-cell phototransistors colored with green and red respectively are found.

Table 1 The short current of a PV cell array and the emitter current of phototransistors (PTs) under red and green light.

Type	Red LED [A]	Green LED [A]	Extinction Ratio
PV	8.24E−12	7.71E−09	936
PT	4.63E−08	4.85E−10	95.5

transistors is smaller than that of photodiodes.

3. Fabrication and Measurements

To demonstrate that the proposed PV cell array has the ability of fast driving of an electrostatic MEMS actuator, we measured the characteristics of the circuit.

We prepared a chip of the PV cell array as follows. On an silicon-on-insulator (SOI) wafer a PV cell array and phototransistors were formed with a standard CMOS process. The area of the diffusion layer of a single PV cell was 10 000 μm^2 and that of a phototransistor was 100 μm^2. To avoid breakdown due to a high voltage, the phototransistors consisted of 10 cells connected in series. The wafer delivered from a foundry was post-processed to mesa-isolate each PV and phototransistor cell with the plasma etching process described in [1]. After the post-process, a PV cell array and phototransistors were colored with green and red lacquer respectively. Fig. 2 is a photograph of the fabricated circuit.

First, the amplification factor of a phototransistor of 100 μm^2 as a bipolar junction transistor was measured and it was found to be 16 when the base current was 1 μA. Next, the short circuit current of a PV cell array and the emitter current of phototransistors under red and green light were measured and Table 1 shows the results. It showed a high extinction ratio, which is good for a discharge circuit. Then, we connected a PV cell array and phototransistors in parallel and measured time to discharge a capacitor. In this measurement, parasitic capacitance (estimated to be 60 pF) was used as a capacitor. Fig. 3 shows the results of discharge. The y-axis indicates the voltage of the capacitor and it dropped when the color of light changed from green to red. As shown in the graph, the capacitor without phototransistors was not discharged well in a short time. On the other hand, the capacitor with phototransistors was discharged in 0.064 s. This result indicates that the discharge circuit of phototransistors using wavelength modulation works successfully.

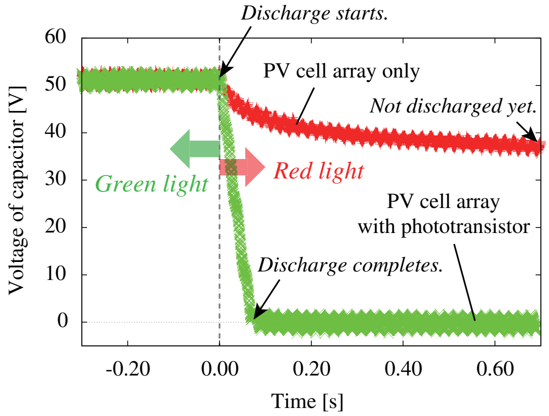

Fig. 3 The voltage of capacitor in the discharge mode. The discharge time is short when the phototransistor is integrated on the circuit.

In these measurements, a demonstration of fast driving of a MEMS actuator was not demonstrated, which is expected to be demonstrated at the conference.

4. Conclusions

We proposed a high-voltage PV cell array integrating discharging phototransistors for fast driving of an electrostatic MEMS actuator by light with wavelength modulation. We have fabricated the proposed PV cell array and conducted measurements. Then we showed that the proposed circuit is effective for fast driving of a MEMS actuator.

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