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MOEMS Vibration Sensor with Organic Semiconductor Readout

A. Kainz[a,*], W. Hortschitz[b], H. Steiner[b], Yi-Hong Hong[c], Chao-Hsuan Chen[d], Hsiao-Wen Zan[d], Hsin-Fei Meng[e], T. Sauter[b], F. Keplinger[a]

[a]*Institute of Sensor and Actuator Systems, TU Wien, Vienna, Austria*
[b]*Center for Integrated Sensor Systems, Danube University Krems, Wiener Neustadt, Austria*
[c]*Institute of Electronics Engineering, National Tsing Hua University, Hsinchu, Taiwan*
[d]*Institute of Electro-Optical Engineering, National Chiao Tung University, Taiwan*
[e]*Institute of Physics, National Chiao Tung University, Taiwan*

Abstract

We present a first proof of principle of applying organic semiconductors as key components in micro-mechanical vibration sensors. The mechanical part of the MOEMS sensor readout is etched into the device layer of an SOI chip and consists of a laterally deflecting inertial mass that features a two-dimensional grid of rectangular holes. An identical grid is evaporated onto a glass chip bonded onto the silicon chip in such way that any deflection of the seismic mass will modulate the light flux passing through the device. The light flux is provided in this case by an OLED and detected by an OPD. It is shown with a proof of concept device that for such sensors organic optoelectronics can replace inorganic ones, which is the starting point for developing a variety of MOEMS sensors based on printed optoelectronic devices.

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Keywords: MOEMS; MEMS; OLED; OPD; Vibration Sensors

1. Introduction

Organic semiconductors offer a large number of advantages compared with inorganic devices. These include large area processing, the possibility to apply them onto flexible substrates as well as being printable with high resolution using standard ink-jet technology. Therefore, the production costs of future devices are potentially low and the throughput very high. A printed organic framework for silicon based microsensors is a worthwhile goal. In this

* Corresponding author. Tel.: +43-1-58801-76697; fax: +43-1-58801-36699.
E-mail address: andreas.kainz@tuwien.ac.at

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prospect, we apply, as a first step, organic optoelectronics (OLEDs and OPDs) to our well-tested micro-opto-electromechanical system (MOEMS) vibration sensor (Fig. 1) [1,2].

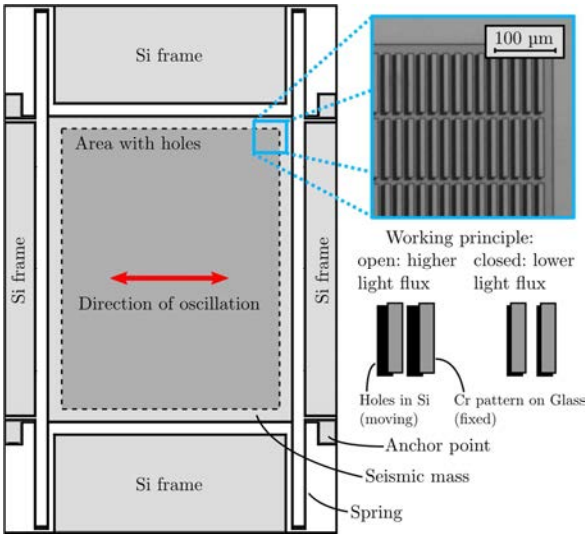

Fig. 1. Schematic of our test structure. Any deflection of the Si inertial mass induces a modulation of the light flux through the holes in the silicon mass (moving) and the stationary apertures made of evaporated chromium on the glass cover. The number of holes determines the sensitivity of the readout. Therefore, a large area with holes is desirable. To effectively use these large areas, OLEDs and OPDs are the best choice.

The readout of the sensor is based on the modulation of the light flux passing through the device by the movement of its inertial mass.

The output signal $\delta U_{out} = \alpha\, N\, l\, \delta x$ is proportional to the relative in-plane displacement δx between the seismic mass and the glass cover and the number of perpendicularly illuminated holes N [1,3]; with l being the length (perpendicular to the direction of movement) of one hole and α a proportionality factor. The sensitivity $\delta U_{out}/\delta x$ depends, therefore, on the effectively illuminated area of the MOEMS. Since OLEDs and OPDs can, in contrast to their inorganic counterparts, be fabricated with active areas of arbitrary sizes, this is especially advantageous for the optical readout of our sensor. The mechanical transfer function of the vibration sensor is given by

$$A(\omega) = \frac{\omega^2}{\omega^2 - \omega_0^2 - i\gamma\omega}, \qquad (1)$$

with ω being the angular frequency, ω_0 the angular resonance frequency, γ the decay constant corresponding to the dissipation of the oscillation energy and i the imaginary unit. Note that, since we apply the device as vibration sensor, the transfer function Eq. (1) has a high-pass characteristic in contrast to the low-pass characteristic of an accelerometer.

2. Setup and Results

In this first approach, the layers for the organic optoelectronics have been deposited via blade coating onto a glass substrate. As transparent electrode materials, carbon nano-tubes (CNT) and aluminium were used [4,5]. To avoid disintegration of the active materials in the atmosphere, the devices are, for now, completely encapsulated in glass (Fig. 2). Their active areas are determined by the overlap of the respective top and bottom electrode and have a size of 2x2 mm². This is the same size as the sensing area of the MOEMS.

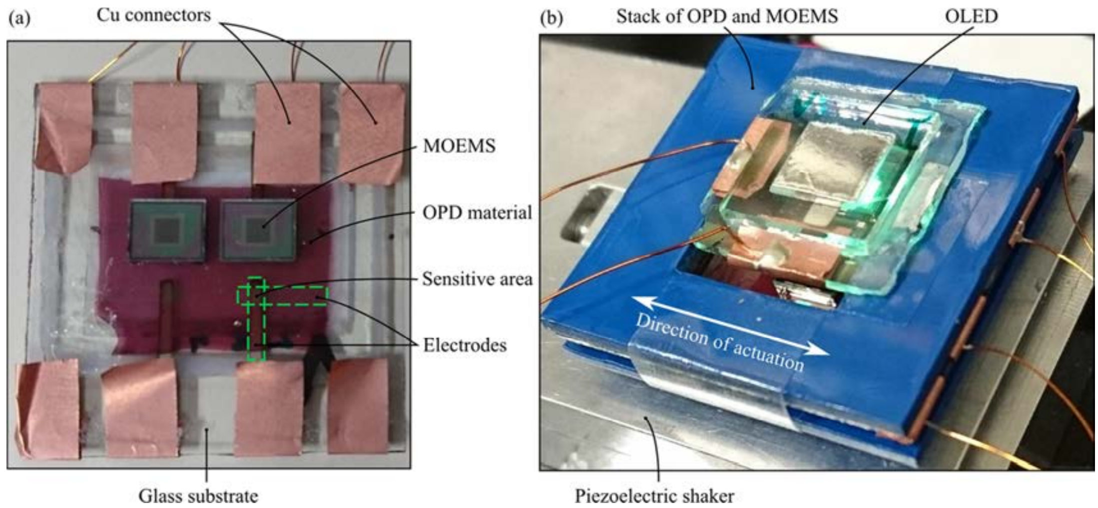

Fig. 2. (a) Large-area OPD with four sensitive regions of which the top two are covered with test chips. The red OPD material is applied onto a glass substrate and contacted with transparent electrodes marked by green dashed boxes. The electrodes overlap in four 2x2 mm^2 areas, resulting in four sensitive squares. The sensors are placed on top of these squares. The connection to the electronics is established via Cu connectors. (b) Setup for measuring the frequency response of the sensors. The actuation along the white arrow is provided with a custom-made piezo driven shaker. The OPD-MOEMS stack is completed here with the green emitting OLED on top.

To stack the components, the MOEMS chips are directly glued onto the OPD. Then the OLED is fixed on the other side of the MOEMS ensuring that the active areas of the organic optoelectronic and the sensing area of the MOEMS are aligned on top of each other. This stack is then mounted onto a custom-made piezoelectric shaker which provides a mechanical excitation for recording the frequency response of the MOEMS (see Fig. 2b).

The bias voltage at the OPD is -1.5 V. The photocurrent produced by the OPD is converted into a voltage via a transimpedance amplifier (OPA404). Its AC component which is proportional to the sensor's transfer characteristic is then recorded via an SR830 lock-in amplifier. Both shaker voltage and lock-in amplifier are controlled by a PC. To avoid degradation of the OLED during the measurement, we set the OLED current to a low 4 mA and increased it to 10 mA for only one measurement.

The results for this very basic setup are shown in Fig. 3a and prove the concept of the OLED and OPD based device. The mechanical resonance frequency of the presented Si structure lies at $f_{\mathrm{res}} = \omega_{\mathrm{res}}/2\pi = 619$ Hz. We compared the performance of the organic components with from-the-shelf inorganic ones. It can be seen that the sensitivity of the configuration using only organic devices is far below the one using only inorganic components. Therefore, we investigated the performance of OPD and OLED separately. The sensitivity obtained with OPD and inorganic LED is comparable to the completely inorganic setup.

Taking a closer look at the OLED, however, we found – using an optical density filter – an inhomogeneous emission of light concentrated at the edges of electrode 2 (Fig. 3b). The reason for this behaviour is that the edges of the electrode were bent towards the other electrode. This causes an unevenly distributed current density and, therefore, unevenly distributed light emission. We assume that, since the emission peaks at the edges of electrode 2, the by far largest part of the light flux is lost outside the sensitive area of the MOEMS chip.

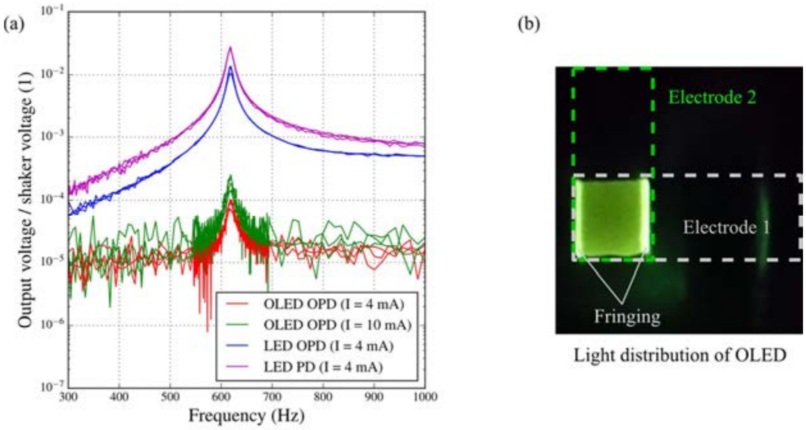

Fig. 3. (a) The transfer function of one test structure measured with the organic optoelectronic components compared to from-the-shelf inorganic opto-electrical components. Every configuration was able to capture the resonance of the MOEMS. Comparing the magenta and blue lines shows that the performance of the OPD is satisfying. The red and green lines, however, indicate issues with the OLED. (b) Fringing of the OLED. The inhomogeneous light emission of the OLED is due to bent edges of Electrode 2 leading to a lower distance between the electrodes along these edges. This causes the current to mainly pass through this region, resulting in a higher light emission.

3. Conclusion and Outlook

Nevertheless, with this contribution we clearly prove the functionality of integrating MEMS with organic components. This is the first step towards highly integrated printable devices which will pave the way for future low-cost fabrication. To ensure reliability with reasonable sensitivity, there are still several technological issues to overcome. In the first place, the fringing problem of the OLED will have to be solved to guarantee a high sensitivity of the current setup. Further steps in the development will be improving the setup with an increasing level of integration and trying to change the OLED/OPD materials and technology to achieve higher robustness and lifetime. For example, by depositing the chromium grid directly onto the OLED, one can omit the glass chips, which reduces the complexity and the number of the fabrication steps.

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