

# Silicon/organic hybrid heterojunction infrared photodetector operating in the telecom regime

Mateusz Bednorz<sup>a</sup>, Gebhard J. Matt<sup>b,\*</sup>, Eric D. Głowacki<sup>c</sup>, Thomas Fromherz<sup>a</sup>, Christoph J. Brabec<sup>b</sup>, Markus C. Scharber<sup>d</sup>, Helmut Sitter<sup>a</sup>, N. Serdar Sariciftci<sup>c</sup>

<sup>a</sup> Institute for Semiconductor and Solid State Physics, Johannes Kepler University, Altenbergerstraße 69, 4040 Linz, Austria

<sup>b</sup> Lehrstuhl für Werkstoffe der Elektronik- und Energietechnik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Martensstraße 7, 91058 Erlangen, Germany

<sup>c</sup> Linz Institute for Organic Solar Cells (LIOS), Johannes Kepler University, Altenbergerstraße 69, 4040 Linz, Austria

<sup>d</sup> Konarka Austria, Altenbergerstraße 69, 4040 Linz, Austria

## ARTICLE INFO

### Article history:

Received 18 September 2012

Received in revised form 1 February 2013

Accepted 12 February 2013

Available online 14 March 2013

### Keywords:

Hybrid system

Photo-detector

Organic electronics

Infrared spectroscopy

## ABSTRACT

The authors report on the fabrication of a silicon/organic heterojunction based IR photodetector. It is demonstrated that an Al/p-Si/perylene-derivative/Al heterostructure exhibits a photovoltaic effect up to 2.7  $\mu\text{m}$  (0.46 eV), a value significantly lower than the bandgap of either material. Although the devices are not optimized, at room temperature a rise time of 300 ns, a responsivity of  $\approx 0.2$  mA/W with a specific detectivity of  $D^* \approx 7 \times 10^7$  Jones at 1.55  $\mu\text{m}$  is found. The achieved responsivity is two orders of magnitude higher compared to our previous efforts [1,2]. It will be outlined that the photocurrent originates from an absorption mechanism involving excitation of an electron from the Si valence band into the extended LUMO state in the perylene-derivative, with possible participation of intermediate localized surface state in the organic material.

The non-invasive deposition of the organic interlayer onto the Si results in compatibility with the CMOS process, making the presented approach a potential alternative to all inorganic device concepts.

© 2013 Elsevier B.V. All rights reserved.

## 1. Introduction

Near-infrared (NIR) photodetectors are required for many applications such as fiber telecommunication, imaging systems, and quality control. Moreover it is clear that the future development of information technology will feature an integration of optoelectronic building blocks, including detectors converting optical signals into electrical ones, into the integrated electronic circuit based on silicon. Presently, inorganic low-bandgap materials (i.e. the rather expensive III–V compound technology) are used in commercial photovoltaic NIR detectors. Despite the excellent performance of these detectors (reaching a responsivity of 1 A/W [3]), the monolithic integration into the well-established

and cheap silicon based CMOS process cannot be easily achieved, due to the crystal lattice mismatch between these two material systems. Moreover the materials such as InGaAs, AlGaAs, and HgCdTe are toxic during various parts of their lifecycle, especially during the mining, extraction and purification stages. Any technology that allows to circumvent these process steps has a huge impact on the ecological footprint of the future information technology, as it drastically diminishes energy consumption and environmental hazardous fabrication steps. An interesting alternative could be the use of all-silicon devices for the telecommunication range (1.55  $\mu\text{m}$ ), which were summarized in a review by Casalino et al. [4]. Such devices are based on various operation principles and exhibited the following responsivities at reverse bias: mid-bandgap absorption (MBA) via ions implantation into Si:  $\text{H}^+$  ( $V = -1$  V,  $R = 8$  mW/A [5]),  $\text{He}^+$  (1.44  $\mu\text{m}$ ,  $V = -20$  V,  $R = 64$  mW/A [6]), surface-state absorption (SSA) via localized states at

\* Corresponding author. Tel.: +49 9131 85 27726.

E-mail address: [gebhard.matt@ww.uni-erlangen.de](mailto:gebhard.matt@ww.uni-erlangen.de) (G.J. Matt).

Si/SiO<sub>2</sub> interface ( $V = -11$  V,  $R = 36$  mW/A [7]), internal photoemission absorption (IPA) in NiSi<sub>2</sub>/p-Si Schottky barrier diodes ( $V = -1$  V,  $R = 4.6$  mW/A [8]) and two-photon absorption (TPA) with a photonic crystal resonator ( $V = -3$  V,  $R = 6$  mW/A [9]).

In this paper we present an alternative concept for extending the sensitivity of Si photodiodes into the NIR, by the introduction of an organic interlayer directly onto the Si substrate. At reverse biases of  $V = -1$  V and  $V = 0$  V, the achieved responsivities were  $R = 2 - 5$  mW/A and  $R = 0.1 - 0.3$  mW/A, respectively. At 0 V, two orders of magnitude larger responsivity compared to our previous efforts [1] based on a p-Si/fullerene diode was observed. The advantages of p-Si/organic junction over all-silicon devices reviewed by Casalino are simpler and cheaper device architectures and a possible operation in a photovoltaic mode at 0 V external bias.

For a direct competition of the proposed technology with commercially available inorganic photodetectors the responsivity has to be increased by at least two orders of magnitude and the bandwidth to the GHz range (which is believed to be limited by RC constant due to the large electrode area in our current device layout). However, due to environmentally and energetically low costs of integration with Si electronic circuits, a reasonable trade off can be reached allowing for cheap production and application when the highest performance is not required.

The compatibility of photodetectors presented in this work with standard CMOS technology is granted by the low temperature deposition of the organic material. The efficacy of direct organic-on-CMOS processing as has been recently shown by Baierl et al. [10] for a CMOS-imager with a photoactive solution-processable polymer working in the visible (535 nm) and NIR (850 nm) range.

## 2. Photodetector device structure, fabrication and experimental methods

A cross-sectional diagram of the silicon/organic heterojunction photodiode is shown in Fig. 1. The substrate was a

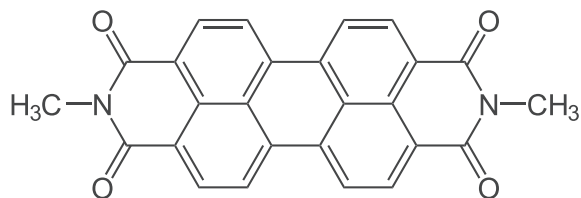


Fig. 2. Chemical structure of the Perylene-diimide derivative: N,N'-Dimethyl-3,4,9,10-Perylenetetracarboxylic diimide (DiMe-PTCDI).

polished (100) oriented, boron-doped (doping conc.  $\approx 10^{15}$  cm<sup>-3</sup>), 250  $\mu$ m thick Si wafer with an annealed (Ohmic) Al contact. The p-Si substrates were cleaned by the RCA-1 process [11] followed by a HF dip and then immediately transferred to the vacuum chamber of a Hot-wall epitaxy (HWE) system. In essence the HWE technique is a semi-closed epitaxy system which can be operated close to the thermodynamic equilibrium [12,13]. As a consequence the weak Van-der-Waals interaction between the organic molecules can dominantly influence the growth dynamics [14] and hence support the formation of large crystalline domains [15,16]. Prior to the deposition of the organic epilayer, the p-Si is annealed in situ at 580 °C for the removal of the hydrogen termination resulting in a clean surface. A  $\approx 25$  nm thick perylene derivative N,N'-Dimethyl-3,4,9,10-Perylenetetracarboxylic diimide (DiMe-PTCDI) thin film is then grown with a deposition rate of 0.4 Å/s and a substrate temperature of 80 °C. See Fig. 2 for the chemical structure of DiMe-PTCDI. The thermal deposition of  $\approx 100$  nm Al on the perylene-diimide as the top contact completes the device fabrication. A test device of the same geometrical dimensions without the organic epilayer, namely Al (annealed)/p-Si/Al, shows neither a rectification nor any photoeffect for temperatures above 207 K, whereas for lower temperatures and particularly at 77 K the observed responsivity for photon energy 0.8 eV was around 0.07 mA/W i.e. around two times lower than the responsivity of the discussed hybrid p-Si/DiMe-PTCDI heterojunctions at 77 K (which was around 20% higher than the value for the hybrid heterojunction at

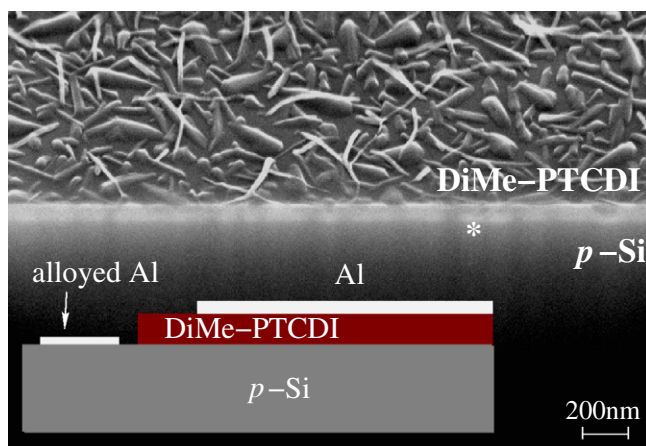


Fig. 1. Bottom: schematic structure of the vertical Al/p-Si/DiMe-PTCDI/Al heterojunction photodiode. Background: scanning electron microscope cross section (viewing angle is 45°) of the DiMe-PTCDI/p-Si heterojunction. A groove through the heterojunction is made with an focused ion beam (FIB). The groove is not 'sharp' and the resulting contrast in the picture is not uniform as seen by the gray regions (one is marked with a \*).

Download English Version:

<https://daneshyari.com/en/article/10566155>

Download Persian Version:

<https://daneshyari.com/article/10566155>

[Daneshyari.com](https://daneshyari.com)