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PbSe Photoconductors: Understanding Behavior and Concept for Upgrade Towards DC Stability

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Summary:

Laser Components is a manufacturer of infrared detectors and with the mission to “Maintain and Upgrade IR Classics”. PbSe polycrystalline mid-wave infrared detectors are integral part of our product portfolio. They are linear p-type photoconductors over wide bias and temperature ranges. Current flows mostly uniform across grains and connecting tissue. Photoconductivity follows the “numbers modulation” model. Practical improvement of the devices is forecasted by using sort of balanced detection scheme.

Keywords: Infrared Semiconductor Detector, PbSe, Mid-Infrared, Photoconductor, Polycrystalline, Uncooled.

Introduction

PbS and PbSe infrared photoconductors belong to the family of thin film photodetectors (TFPD) and have been around for decades and successfully used in commercial and defence applications since. However, industrial usage of those materials has been based on RoHS exemptions and therefore strong efforts towards replacement were initiated. PbS and PbSe have been challenged for RoHS several times, but there is good news: Another exemption until July 2028 has been recommended and a longer-term co-existence of lead salt detectors and new DWRS (Detectors Without RoHS Substances) is forecasted. [1]

This paper is dedicated to PbSe and there is a mystery that needs to be explained: Typical D* for an uncooled PbSe device is 1.8 x 10^{10} Jones which is well above competing uncooled mid-wave infrared (MWIR) photodiodes. So, why do polycrystalline devices outperform single crystal based devices? Recently, broader investigations have been started in the community [2] triggered partially by A. Rogalski who called for more detailed information on PbSe [3]. This paper will contribute to a better understanding of the material and uses data from [4].

In practical use, dynamic behaviour becomes important and this paper will pave the road towards PbSe detectors with more “usability” as well.

Material Related Investigations

Basically, PbSe photoconductors belong to the group of TFPD (thin-film photodetectors). Complex material characterization has been performed at several stages of CBD (chemical bath deposition): Deposited, oxidized and iodized. The deposited film by itself has no photosensitivity. Iodization of this film does not result in photoconductivity. A weak sensitization is achieved by oxygen. Full sensitization requires subsequent iodization. Effects on carrier density, mobility and resistivity can be seen in Tab.1

Tab. 1: Hall effect data of PbSe (23°C, p-type carriers)

Production step	Relative Concentration	Relative Mobility	Relative Resistivity
Deposited	1.000	1.0	1
Oxidized	0.024	11.3	3
Iodized	0.018	0.5	110

Obviously, the resistance plays a major role in photosensitivity. In a typical application, the detector resistance is changed by 0.1% under illumination. We found out as well, that iodization is mandantory for a linear device. Our ma-

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terial is always p-type with a typical film thickness of 1 µm. No signatures of barriers could be found in I-V characteristics. Surface XPS did indicate a mixture of PbO with SeO2, below it is mostly PbSe. A weak iodine signal is present as well. Photocurrent curves vs. 1/T are parallel for different light intensities. This is the signature of the number model. So, photoconductivity is achieved by increased hole concentration and increased hole lifetime since electrons are trapped.

Fig. 1 does give a visualition of what is going on inside the material structure: Deposition does result in crystallites that are stacked very closely. Oxidization starts to loosen this structure and after iodization it has turned into “grains that are surrounded by lots of connecting tissue”.

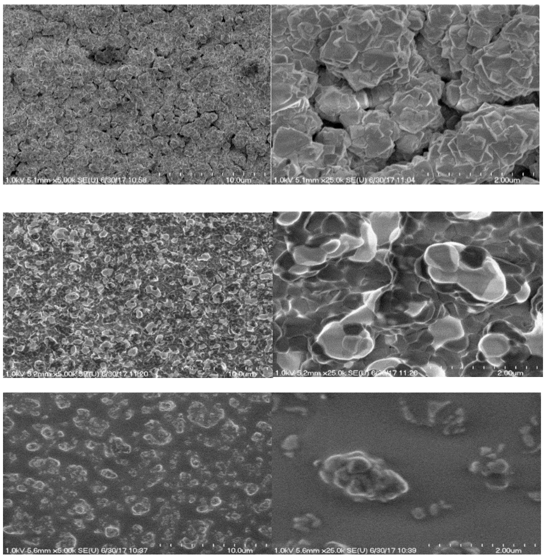

Fig.1. SEM images of PbSe at various production steps. Top: Deposited. Middle: Oxidized. Bottom: Iodized

Kelvin probe microscopy images do indicate that grains have higher electron energy which leads to the assumption that they act as traps. However, it turned out as well, that current does flow mostly uniform across grains and tissues.

Improved Usability

PbSe detectors have to follow recent user expectations as best as possible and recent users do expect a stable baseline after switch on. We followed an old approach to dampen the effects of temperature variations without using Peltier cooling.

PbSe elements are usually driven in a voltage divider configuration, i.e. the PbSe and a load resistor are connected in series. The idea is to use a blinded PbSe element as load resistor. In case of identical twins, the resistance among load and photoresistor will always be matched over temperature and bias will be constant. In some aspects, this can be seen as “balanced detection”. At pretests, the DC signal was found to be stable within 0.5 % immediately after switch on. This result was surprising to experienced users, since they have been used to initial settling times of approximately 10 minutes. [5]

Results

Transport in PbSe has been investigated. In some aspects, our data show consistency with [6]. As a little special, we found a grain-tissue morphology, a mostly uniform current and the importance of iodization for a linear device. [4] Evidence for the numbers model has been found in contrast to the standard literature [3], that favors the Petritz model.

We report a “balanced” approach that results in PbSe detectors with a stable baseline immediately after switch on. At the moment, we are working on scaling up.

Our PbSe devices work well. However, we have been unable to find barriers as predicted by recent models. [6] So, further investigation by the community is needed.

Acknowledgement

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