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ams' Technology Concepts on Monolithic Integrated Photosensors

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ams AG is a global leader in the design and manufacture of advanced sensor solutions, which are at the heart of the products and technologies that define our world today – from smartphones and mobile devices to smart homes and buildings, industrial automation, medical technology and connected vehicles. To build global leadership in optical sensing, ams is driving integration of sensor technologies into monolithically integrated solutions. This paper will provide an overview of ams' integrated photosensor concepts including 3D integration, spectral sensing and radiation hard concepts.

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1. Introduction

ams AG designs and manufactures high-performance sensor solutions for applications requiring the highest level of miniaturization, integration, accuracy, sensitivity and lower power. Our comprehensive solutions take sensing to the next level by providing a seamless interface between humans and technology. Products include sensor solutions, sensor ICs, interfaces and related software for mobile, consumer, communications, industrial, medical, and automotive markets. For ams AG innovation in sensor- and integration technology as well as in microelectronics is mandatory for building high performance integrated systems. With the ongoing miniaturization of CMOS technologies the need for integrated optical sensors on smaller scale CMOS nodes arises. In the following paragraphs recent ams AG developments in optical sensor technologies including integration concepts of different optoelectronic modules, filter and antireflective coatings (ARCs) as well as 3D integration using Through Silicon Vias (TSVs) are reported.

2. Monolithic integrated photosensors

Monolithic integrated photodiodes (PDs) are key components of ams' miniaturized smart systems. Their broad field of applications makes them ideal candidates for devices that incorporate functions of sensing, actuation and control integrated at a microelectronic level. Photosensor applications include display management, 3D sensing, medical diagnostic equipment, industrial processes and controls, health/fitness monitoring products and automotive applications. Such optical sensors typically use existing CMOS technologies with add-on modules like ARCs and filters. 3D integration of photo sensors allows for combinations of CMOS process and photo sensor process as circuitry and photo sensors are processed on different wafers.

2.1 Multi-junction photodiodes

Figure 1 shows a triple well PD processed in the 0.18µm HV-CMOS process options of ams. Only standard process steps are used. The only modification is the opening of the passivation nitride layer on top of the PDs in order to minimize multiple reflections and interferences in the illumination path in the dielectric layer stack between top wafer surface and the silicon based diodes. Short-circuiting selected pn-junctions as indicated in the figure suppresses the photocurrent contribution from these junctions. Depending on which junctions are connected together the peak of the optical response can be shifted, thus enabling a rough RGB filter function without any filters applied [1].

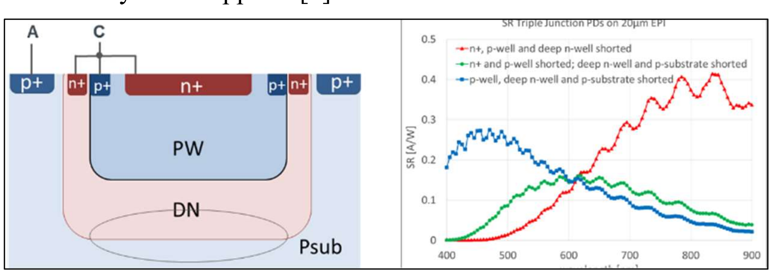

Fig. 1. Schematic triple well PD (left) and according spectral responsivity (right).

2.2 UV photodiodes

In figure 2 the schematics of a UV sensitive PD [2] is depicted. By activating just the top pn-junction while short-circuiting all other junctions, visible and infrared parts of the spectrum are suppressed while the PD is most sensitive in the UV spectral range between 250nm-400nm. This is shown in the spectral responsivity curve on the right hand side of figure 2. Applications of UV sensitive PDs in conjunction with on-Si interference filters range from UV index sensors, e.g. wearables which change color when exposed to potentially harmful dose of UV sunlight, to UV-A/B/C dosimeters or scanners.

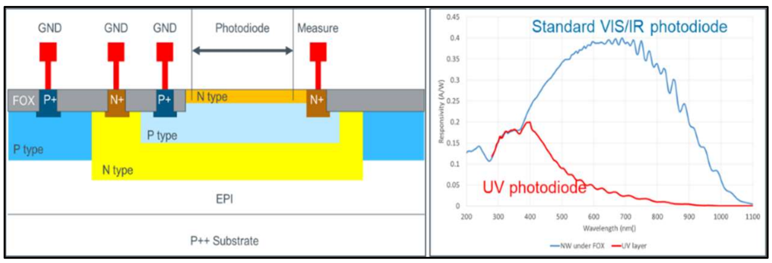

Fig. 2. Schematic of UV PD (left) and according spectral responsivity in comparison to a standard PD (right).

2.3 Radiation hard photodiodes

Special PD developments have been made for medical computer tomography (CT) scanners. According to the schematic overview of the CT setup depicted on the left hand side of figure 3, X-rays penetrate the human body and are transformed into visible light by a scintillator. The visible light is then detected by PDs. As a certain fraction on X-rays penetrates the scintillator array, special care must be taken in order to make the PDs radiation hard. Very good results for spectral responsivity, leakage current and radiation hardness have been received with a 3D stacked backside illuminated PD shown on the right hand side of figure 3, where PD and readout circuitry are processed on two different wafers. PDs of similar performance are also available in a monolithic integrated concept [3].

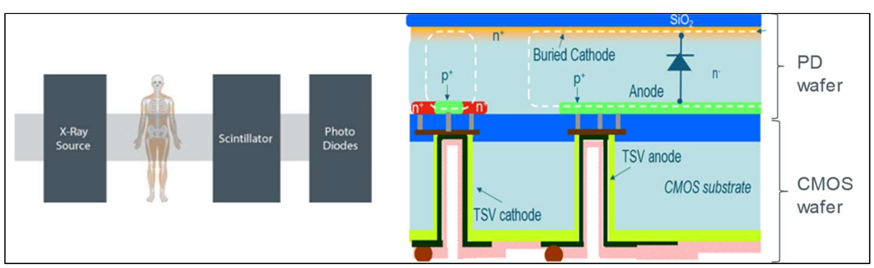

Fig. 3. Schematic CT (left) and 3D integrated PD for CT scanners (right).

2.4 PIN photodiode integration concept

Exploitation of the advantages of p-intrinsic-n (PIN) PDs, such as high bandwidth and dynamic range, necessitates the use of very low-doped base materials. Figure 4 shows the schematic layout of ams AG's PIN photodiode integration concept. Starting with lowly p-doped (p-type intrinsic) EPI material, we need just one additional mask and ion implantation process step in order to provide doping concentrations very similar to standard CMOS substrates to areas outside the photo-active regions. Thus full functionality of the standard CMOS logic can be guaranteed while the photo detectors highly benefit from the low doping concentrations of the intrinsic EPI. The major advantage of our integration concept is that complete modularity of the CMOS process remains untouched by the implementation of PIN photodiodes [4,5].

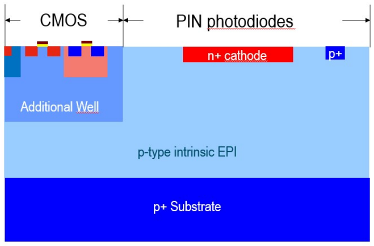

Fig. 4. Schematic layout of PIN photodiode integration concept.

3. Antireflective Coatings

To further enhance the photo sensor's quantum efficiency different ARC concepts can be applied as shown in figure 5. Most efficient in suppressing multiple reflections is the Bottom ARC (BARC), where the reflected fraction of the optical power is minimized by removing the whole dielectric stack on top of the PD. The Bottom ARC layer, which functions as $\lambda/4$-plate, is subsequently deposited directly on Si [6]. Applied to the PIN PD shown in figure 4, an external quantum efficiency of almost 100% could be achieved. Figure 6 shows the measured responsivity values of the PIN PD together with the maximum achievable theoretical value Smax for Si (dashed line) and the external quantum efficiency (EQE) of 99% [7].

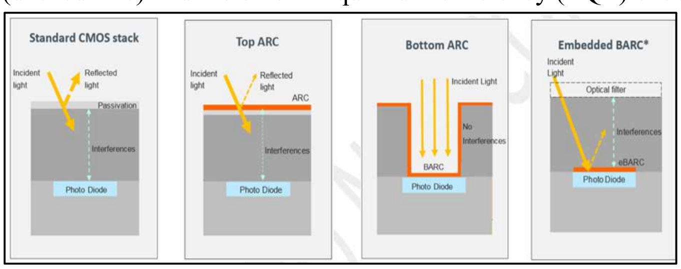

Fig. 5. From left to right: standard PD backend without ARC; Top ARC; Bottom ARC; embedded BARC.

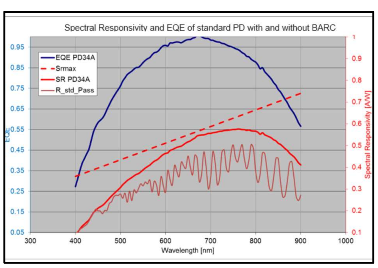

Fig. 6. Spectral responsivity and EQE of SR of a PD with standard backend and with BARC.

4.Filters

Implementation of filter technologies is key for applications such as color sensing, spectral imaging, and ambient light sensing. The required spectral transmission characteristics of the filters is frequently determined by industry standards and customer requests. State of the art and commercially available interference filters deposited on glass or specifically absorbing glasses can be used for such applications. However, for monolithic integrated smart systems utilizing more than one filter, the required integration density can't be reached with these widely used filters on glass substrates. The filters have to be part of the CMOS fabrication process, taking advantage of the available lithography steps. ams AG offers a large variety of organic and inorganic filters as part of their CMOS fabrication processes, which can be utilized as stand-alone filters together with a PD, or in combination as stacked filters. For instance, an organic infrared blocking filter on top of a photopic interference filter can help blocking the unwanted infrared portion of an incandescent light source. Figure 7 shows the spectral response of ams AG's tristimulus filter and its application in display management.

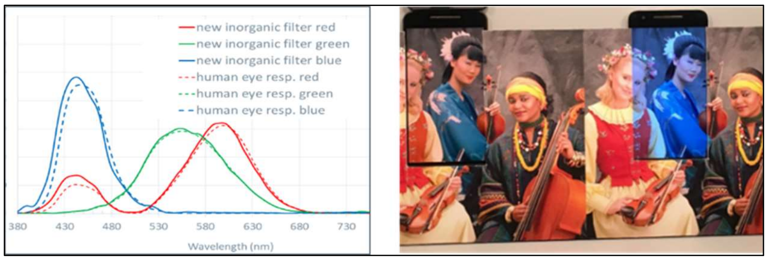

Fig. 7. Spectrum of tristimulus filter (left) and application in display management (right).

Another application for integrated filters is spectral sensing. As the number of different inorganic filters on a chip is in principle not restricted, several different channels can be built, which sense only a narrow portion of the spectrum as shown in figure 8.

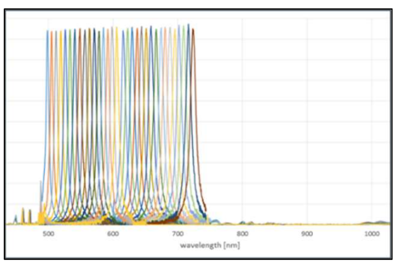

Fig. 8. Spectrum of an integrated 32 channel spectrometer.

5. 3D Integration of optical sensors

3D/TSV technology enables new integrated sensor IC applications with reduced footprint and improved performance enabling miniaturized and cost-effective smart systems. ams AG offers 3D integrated optical sensors by Wafer-to-wafer bonding and Backside Redistribution Layer techniques [8] as shown in figure 9.

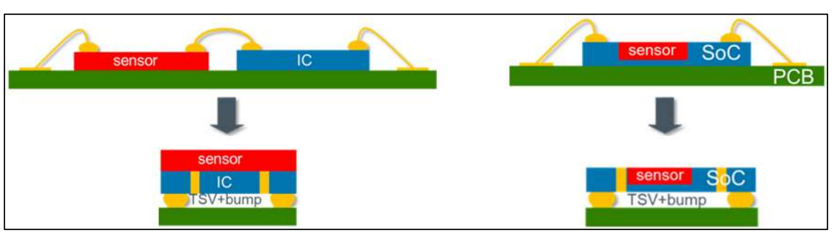

Fig. 9. Schematics of Wafer-to-wafer bonding (left) and Backside Redistribution Layer technique (right).

To demonstrate the better optical performance of 3D integrated optical sensors Figure 10 compares the optical response of a 3D integrated ambient light sensor (ALS) using Backside Redistribution

Layer and Wafer Level Packaing (WLP) to an identical ALS in a standard optical (shellcase) package. Significantly higher optical sensitivity of the 3D integrated ALS due to the missing package glass can clearly be observed.

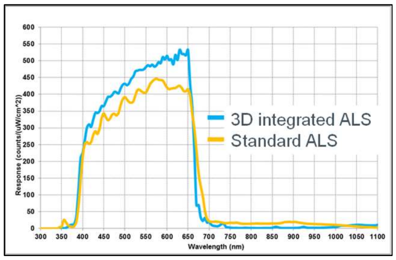

Fig. 10. Optical response of a 3D integrated ALS including WLP and an ALS in standard package.

6. Summary

This paper presents developments in optical sensor technologies including monolithic integration concepts of optoelectronic modules, filters and antireflective coatings as well as 3D integration. The broad portfolio of available combinations enables customer specific solutions for many different applications and leverages the realization of smart systems. Optimized photo sensors can be combined with application tailored on-chip filters and/or coatings using 3D integration and Wafer Level Packaging options.

References

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