A monolithic BSI time-of-flight sensor supporting a resolution of up to 160x120 pixels with on-chip data processing enabling stand-alone or sensor fusion applications

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Abstract

In this paper a monolithic 3D sensor with a package size of 7.0 x 4.3 x 3.0mm is presented. The small form factor is achieved by stacking multiple dies on top of each other. The system enables ranging from 10mm up to 10m at a frame rate of 120Hz at a resolution of 20x15. A resolution of up to 160x120 can be achieved by using time multiplexing. At an ambient light level of 50klux and target reflectivity of 30%, a maximum distance of more than 5m can be reported.

The VCSEL driver is optimized to emit a high optical peak power of 26W at a pulse-width of 440ps without exceeding the class 1 eye safety limit. A micro lens array on the emitter side is implemented to achieve uniform illumination of the FOV of about 70deg. The sensor is based on a 45nm SPAD technology which is connected by hybrid bonding to the 22nm processing chip. A SPAD pitch of 10um and a PDE of 12% at an excess bias voltage of 2.3V and 940nm is achieved. Data processing is supported by 300 time-to-digital converters and on-chip processors that allow run-time monitoring of histograms, on-chip target peak detection and histogram data compression.

The system consumes in standby 27uW and in operation 110mW at 30Hz without ambient light. It is suitable for stand-alone operation as well as sensor fusion, where RGB and time-of-flight camera are used to upscale the resolution of the 3D image significantly.

I. Introduction

In this paper a monolithic 3D sensor with a package size of 7.0 x 4.3 x 3.0mm is presented (Figure 1). It enables ranging from 10mm up to 10m at a frame rate of 120Hz at a resolution of 20x15. A resolution of 160x120 can be achieved by using time multiplexing. At an ambient light level of 50klux and target reflectivity of 30% a maximum distance of more than 5m can be reported. The small form factor is achieved by stacking multiple dies on top of each other. The main layer is a power management system which includes the VCSEL driver with a stacked high power VCSEL. The PMU carries the sensor die which consists of the backside illuminated SPADs connected by hybrid bonding to a 22nm processing unit connected. A micro lens array on the emitter side is implemented to achieve uniform illumination of the FOV of about 70deg. It is optimized to emit narrow pulse-width, high optical peak power. The receiver optics is based on wafer-level optics and includes the 940nm bandpass filter. The corresponding block diagram is shown in Figure 2.

II. Module architecture

A. PMU and VCSEL driver

The module includes a power management unit to supply the SPAD sensor, a flash memory and a VCSEL driver operating a high power VCSEL which is stacked directly on the PMU die. Optical peak power is important for achieving high SNR in time-of-flight systems. The implementation is therefore optimized to emit a high peak power up to 26W at a pulse width of 440ps without exceeding the class 1 eye safety limit. These power numbers are achieved by using a multi-junction VCSEL.

B. Sensor

The sensor is based on a 45nm SPAD technology which is connected by hybrid bonding to the 22nm processing chip (Figure 3). A SPAD pitch of 10um and a PDE of 12% at an excess bias voltage of 2.3V and 940nm is achieved. Each macropixel consists of 8x8 SPADs which are connected to its own TDC, processor and histogram memory implemented on the 22nm processing directly underneath. In order to allow on-chip histograms and processing a windowing scheme is used during integration cycle. Data processing is supported by 300 time-to-digital converters and allows run-time monitoring of histograms, on-chip target peak detection and histogram data compression which allows to stream distance or histogram data via standard data interface such as SPI avoiding a high data rate interface such as CSI.

III. Measurements

The system consumes in standby 27uW and in operation 110mW at 30Hz without ambient light. An example is given in Figure 4. Generally, overall power consumption scales with performance. In indoor application with 15Hz the power consumption can be as low as 150mW while at 50klux, 30% reflectivity, a frame rate of 10Hz max distance of 5.3m the power consumption increases up to 600mW. Sensor fusion technique takes advantage of the combination of low resolution TOF and RGB camera which allows to upscale the resolution of the 3D image significantly. Demonstration for indoor and outdoor operations are shown in Figure 6.

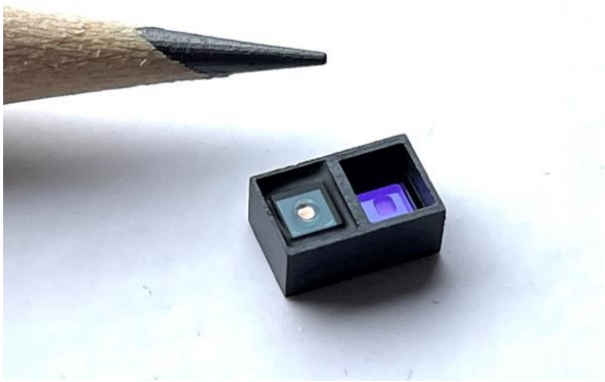

Figure 1 - Package of module.

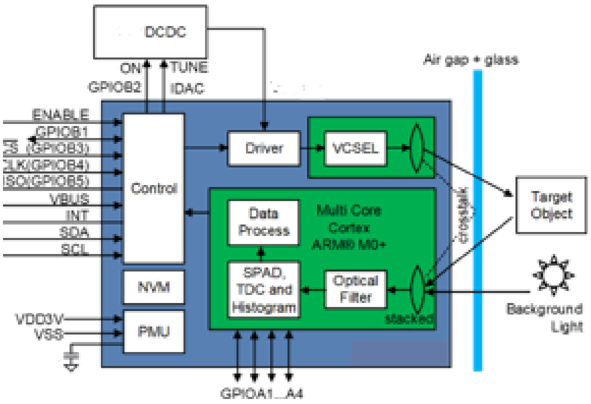

Figure 2 - Block diagram of time-of-flight sensor.

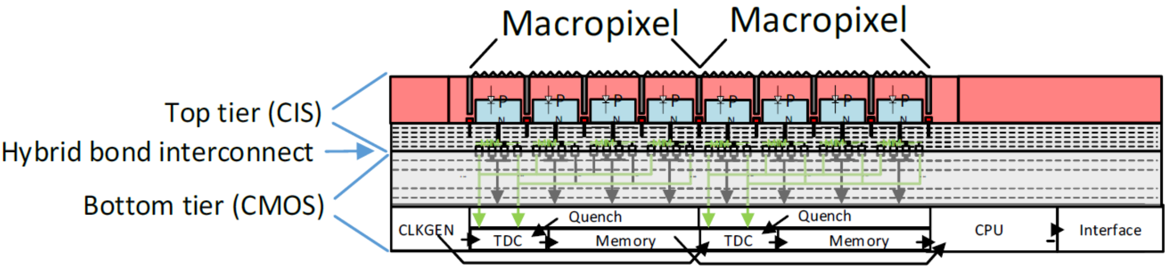

Figure 3 - Cross section of BSI sensor.

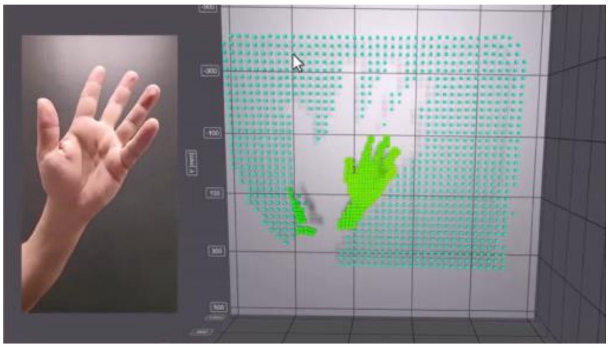

Figure 4 - 3D point cloud demonstration.

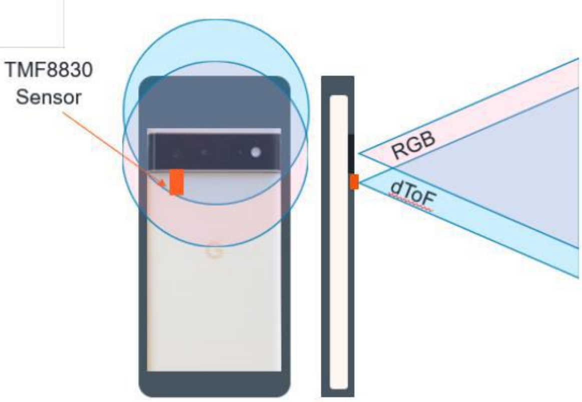

Figure 5 - Sensor fusion application. Low resolution TOF sensor and RGB camera allow to generate high resolution 3D image.

Figure 6 - Indoor and outdoor demonstration of resolution upscaling by using sensor fusion mode