TeraLine—Single Detector for Multicolor Terahertz (THz) Imaging

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Active multi-color Terahertz (THz) imaging technology has a very large potential for inspection of composite materials. The single pixel detector developed in the TeraXplore project and integrated in a 0.18 µm CMOS process was used to build a demonstrator for THz imaging. Furthermore, a new version of the single pixel detector is currently being implemented in 55 nm CMOS technology.

Terahertz (THz) imaging technology is increasingly being used in the fields of non-destructive material inspection (especially composites), security (people screening), medical diagnosis (skin cancer or diabetes screening) and food inspection (detection of contaminants or decayed products). THz imaging has many advantages over traditional inspection technologies like microwave, ultrasound or x-ray. For example, it penetrates electrically non-conductive materials and is safe to use. THz multispectral imaging is particularly interesting because specific materials have a precise “fingerprint” in the THz spectrum, and thus features become visible that are not present in a monochromatic image, which allow robust identification.

In this report, we present a demonstrator that was built with a THz detector obtained from last year’s CSEM TeraXplore Multidisciplinary Integrated Project (MIP). The CMOS-based single point detector uses the “direct detection method”, i.e. the detector consists of an antenna and a CMOS-based RF receiver. The demonstrator setup is shown in Figure 1.

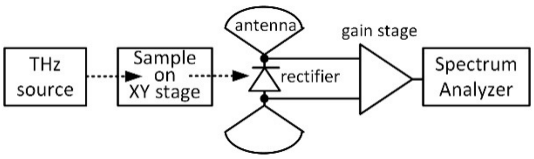

Figure 1: THz demonstrator setup.

An off-the-shelf THz source was used. The THz output can be tuned to a frequency between 325 GHz and 500 GHz. In order to reduce the impact of the rectifier’s flicker noise, 200 kHz on-off keying is applied to the source signal. The measurement was done in transmittance mode, i.e. the sample is located between THz source and detector. As a single point detector is used and the sample is moved with a XY stage to enable scanning of the entire sample. The output of the detector was amplified and then observed with a spectrum analyzer, and averaged over 1 second.

Images of several different materials, such as a composites with defects, polymers and PV cells were taken with the demonstrator. Figure 2 shows a THz image of a glass fiber composite plate with 3 holes of different sizes and a metal plate attached to it. The picture was taken with a source frequency of 425 GHz and a pixel size of 0.5 mm. It can be observed that the resolution is around 1.5 – 2 mm due to the strong diffraction effects at this wavelength (0.66 mm). The different defects can be distinguished in the image (missing material, metal or polymer inserts).

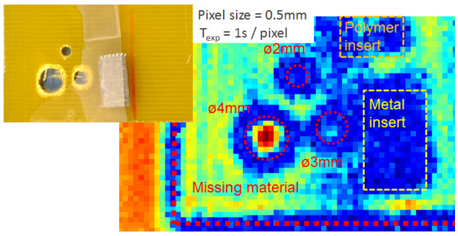

Figure 2: (left) image of glass fibre composite plate; (right) THz image.

Different detector types were developed within TeraXplore and implemented in 0.18 µm CMOS technology. Measurements of this test chip have shown that the most promising detectors are the Poly-Gate-Separated (PGS) Schottky diode and the diode-connected MOS transistor. The optimum frequencies of operation are in line with the results of simulations. The performance of the detector is comparable to state of the art shown in Table 1.

Table 1: Detector performance vs state of the art.

	Response	**NEP**	**Freq**	**Detector**
Y. Zhan [1]	323 V/W	29 pW/√Hz	280 GHz	Schottky
E. Seok [2]	200 V/W	100 pW/√Hz	180 GHz	Schottky
R. Han [3]	250 V/W	33 pW/√Hz	280 GHz	Schottky
TeraXplore	158 V/W	65 pW/√Hz	425 GHz	Sch. / FET

As better performance is expected for smaller transistors [4], a new detector test chip was designed in TSMC 55 nm technology. Because of the lack of simulation models for THz frequencies, different sizes were implemented for each type of detector. As in the previous test chip, narrow-band patch antennas were integrated on the chip with the center frequencies 375 GHz, 425 GHz, and 475 GHz. This test chip will be taped out in September 2017. First measurement results are expected by the end of the year.

Work also continued on the development of a broadband antenna, which supports a frequency range from 300 GHz to 500 GHz. The first approach was 3D printing of the helix antenna, followed by electro-less deposition. However, this structure has problems with mechanical stability. Therefore a second approach was employed to print the helix in metal on the outside of a cylinder. Several samples were printed on plastic and silica rods. The metal layer of the tested silica samples was found to have good conductivity. Antenna characterization results are expected later this year.

[1] Y. Zhang, *et al.*, “Schottky diodes in CMOS for terahertz circuits and systems”, RWS IEEE Radio and Wireless Symposium (2013).

[2] E. Seok, *et al.*, “Progress and challenges towards terahertz CMOS integrated circuits”, IEEE Journal of Solid-State Circuits, 45 (2010) 1554.

[3] R. Han, *et al.*, “A 280-GHz schottky diode detector in 130-nm digital CMOS”, IEEE Journal of Solid-State Circuits, 46 (2011) 2602.

[4] A. Boukhayma, *et al.*, “A 533 pW NEP 31×31 pixel THz image sensor based on in-pixel demodulation”, ESSCIRC European Solid State Circuits Conference (2014).