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AN ULTRA-FAST AND WIDE-SPECTRUM LINEAR ARRAY DETECTOR FOR HIGH REPETITION RATE AND PULSED EXPERIMENTS

M. M. Patil*, M. Caselle, E. Bründermann, S. Funkner, B Kehrer, G. Niehues, W. Wang, A-S Müller and M. Weber, Karlsruhe Institute of Technology, Karlsruhe, Germany
C. Gerth, DESY, Hamburg, Germany
D. Makowski, A. Mielczarek, University of Technology, Lodz, Poland

Abstract

Photon science research at accelerators is influenced radically by the developments of sensor and readout technologies for imaging. These technologies enable a wide range of applications in beam diagnostics, tomography and spectroscopy. The repetition rate of commercially available linear array detectors is a limiting factor for the emerging synchrotron applications. To overcome these limitations, KALYPSO (Karlsruhe Linear arraY detector for MHz rePetition rate SpectrOscopy), an ultra-fast and wide field-of-view linear array detector operating at several mega frames per second (Mfps), has been developed. A silicon microstrip sensor is connected to custom cutting-edge frontend ASICs to achieve unprecedented frame rate in continuous readout mode. In this contribution, the third generation of KALYPSO will be presented.

INTRODUCTION

Electron bunches stored in storage rings over long time scales exhibit short-term and long-term dynamics. During low-alpha-mode operation, the electron bunches interact with their own radiation field, which leads to the so-called microbunching instability [1]. In this process, bursts of synchrotron radiation are observed in the terahertz (THz) range, with several orders of magnitude higher than conventional synchrotron radiation. Electro-optical spectral decoding (EOSD) is one method employed for THz spectroscopy [2]. A bottleneck of such an experiment (Figure 1) is the single shot detection at MHz repetition rate. Conventional detectors are incapable of operating at Mhz repetition rates. Thus a detector system has been developed which combines unprecedented repetition rate, excellent spatial resolution and continuous data streaming. The applications of such a detector extend from laser characterization and transients, beam diagnostics to microscopy for classification of biological cells [3].

KALYPSO DETECTOR

KALYPSO had been originally developed for upgrading the EOSD experiment by replacing the commercial camera with low frame rate at KIT's synchrotron light source KARA [2]. The complete system consists of a modular architecture that includes three main components: the KALYPSO mezzanine detector board, the readout card equipped with a Field programmable gate array (FPGA) for data acquisition and processing, and the heterogeneous DAQ system consisting of FPGAs and GPUs connected via PCI-Express [4]. The original version of KALYPSO is based on a slightly modified design of the GOTTHARD frontend ASIC [5] and achieves a maximum frame-rate of 2.7 MHz with 256 pixels. The next version of KALYPSO has an operating frame-rate over 1 Mfps and consists of a wide linear-array with 1024 pixels with a pitch of 25 μm silicon sensor connected to eight ASIC readouts (cf. Figure.2). The silicon sensor was developed at KIT and fabricated at FBK, Trento (Italy).

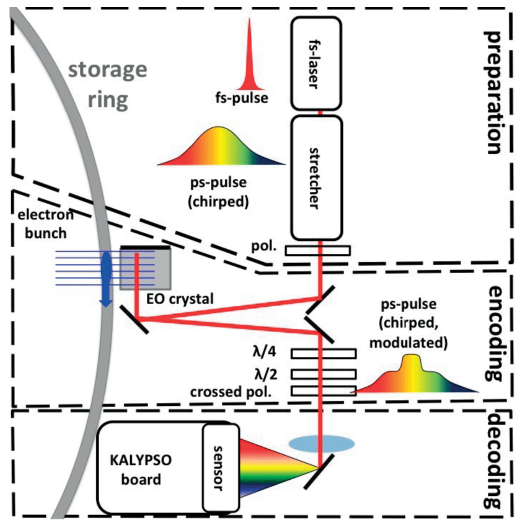

Figure 1: EOSD experimental setup at KARA.

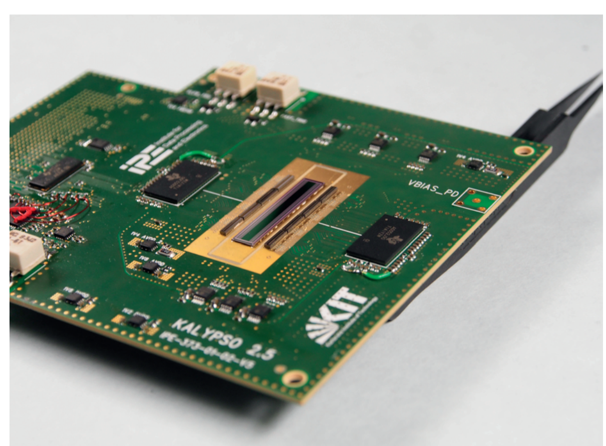

Figure 2: KALYPSO v2.5 under development.

* meghana.patil@kit.edu

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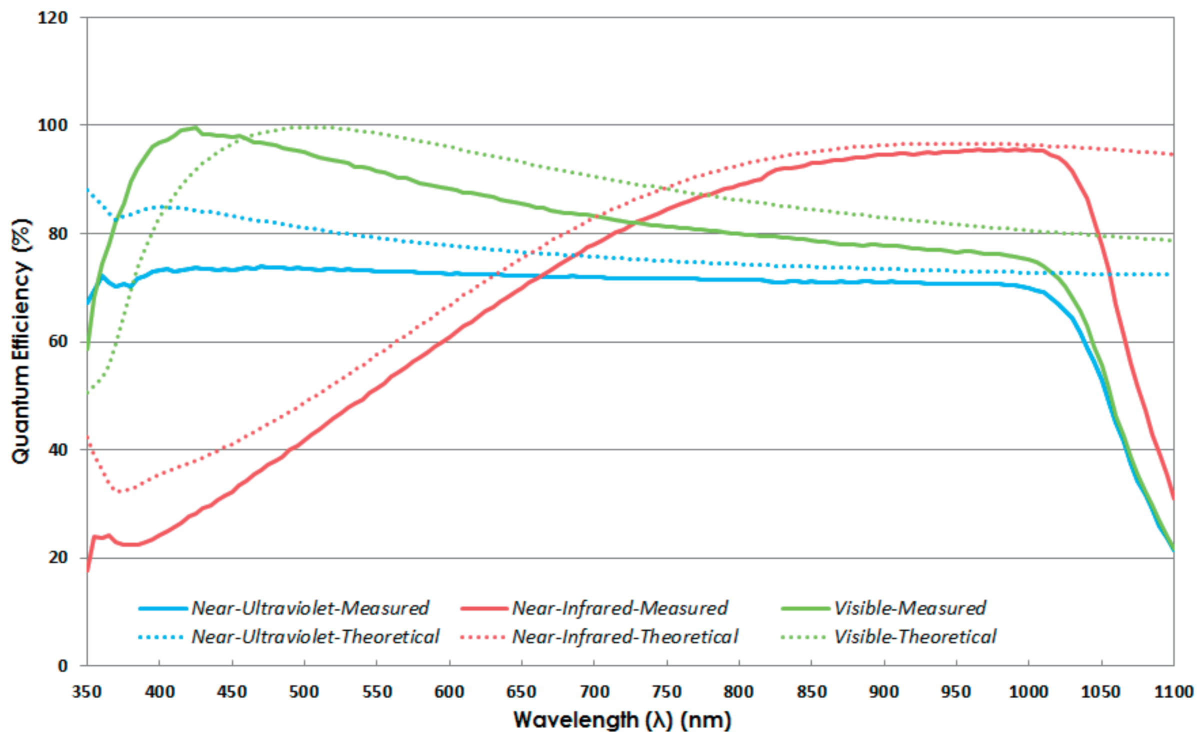

Figure 3: Theoretical and measured quantum efficiency of the three wafers optimized for near-UV, visible and near-IR.

Silicon Microstrip Array

Silicon sensors are widely used to detect particles and photons: in particle physics experiments for charged particles, in astrophysics and on satellites for gamma and x-rays, at synchrotrons for photons and electric field transients. As an important part of detection, a sensor with high quantum efficiency and with good spatial and time resolution must be designed. Good spatial resolution is extremely necessary to resolve electron bunches with sub-ps time resolution and optimized photon transmittance is necessary for applications using wavelengths in the near-IR and near-UV region. As indicated in [6] silicon has optimal wavelength responsivity from 800 nm to 1000 nm. Hence, it is necessary to optimize the quantum efficiency for applications using wavelengths in the near-IR and near-UV region.

A silicon sensor with a pitch of 25 μm has been designed and optimized for the parameters mentioned. The readout pitch on the front end chip is fixed to 50 μm, so an interleaved sensor for ASIC integration is required to adapt to this pitch [7]. Semiconductor materials such as GaAs and Si have high reflectivity of approximately 30 to 40 %. An Anti-reflection (AR) coating layer should be deposited on the sensor surface to reduce reflectivity and improve sensor efficiency [8]. The wafers fabricated have been optimized for near-UV (350 nm), visible (400 - 800 nm), near-IR (900 - 1050 nm) spectral ranges.

Figure 3 presents a comparison between theoretical and measured total quantum efficiency (QE). The measurements were performed on the test structures present on the wafer. It can be seen that the measured QE follows the theoretical QE regime with slight offsets. These offsets are due to the thickness of the wafer taken into consideration during the theoretical estimation. An average QE of 90 % can be seen for the visible spectrum, an average of 90% for the near-IR spectrum and a uniform 72 % for near-UV spectrum.

CONCLUSION

A wide spectral and ultra-fast detector KALYPSO v2.5 has been developed and will soon be installed in various synchrotron facilities. The new detector will improve dramatically both the detection and resolution of its predecessor system and therefore will be employed in beam diagnostics experiments which require a wide spectral regime with fine spectral resolution and MHz repetition rates. A new ASIC has been designed which will increase the repetition rate by factor 10 is currently in production stage [9].

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