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DEPFET sensor with intrinsic signal compression developed for use at the XFEL free electron laser radiation source

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ABSTRACT

A new DEPFET detector-amplifier structure with strongly non-linear characteristics is presented. It will be used as basic element of an X-ray pixel detector at the new XFEL free electron laser radiation source to be constructed in Hamburg, Germany, providing at the same time single X-ray photon detection and high dynamic range even when operated at readout frequency up to 5 MHz. This is possible due to the new detector concept that adds to the excellent DEPFET properties – combined function of detector amplifier and data storage, full sensitivity over whole bulk, non-destructive readout, low serial noise and absence of reset noise – the new features of very large charge handling capability and signal compression. Concept and design will be presented and properties demonstrated by extended computer simulations.

1. Introduction

The development to be described has been initialized by requirements of experiments at the future X-ray free electron laser (XFEL) X-ray source in Hamburg. Due to its superconducting technology this accelerator has a rather uncommon bunch structure (see Fig. 1). The complete detector readout has to be performed within 200 ns and the (in some experiments) from pixel to pixel strongly varying intensity bring additional requirements. A pixel with one single photon (of 1 keV) has to be clearly distinguished from one with no photon and at the same time another pixel with up to 10,000 photons should still be in the range of sensitivity. In order to be able to accomplish such a task within a very limited output voltage range (of a few hundred millivolts) high amplification for small signal charges and very strong signal compression is needed. In addition charge collection has to be fast, so that the measurement can be accomplished within the available 200 ns.

Due to the speed requirement every pixel has to have its own readout channel. This will be accomplished by connecting pixel sensor and ASIC electronics by means of bump bonding. The signal readout chain with the associated performance will be presented in separate conference contribution. Here we will restrict ourselves on the sensor part that has been designed and its function verified by extensive computer simulations.

Hexagonal geometry and combination of a DEPFET with a drift section has been chosen in order to make charge collection fast. The diameter of 236 μm was forced on us by the specifications of the bump bonding technique in the IBM C4 process. Non-linearity is accomplished by forming the internal gate in such a way that small charges assemble perfectly below the transistor channel, while large charges spread also below the source where they are almost ineffective in modulating the transistor channel.

2. DEPFET principle

The basic principle of a DEPFET (Ref. [1]) is illustrated in Fig. 2. A field effect transistor (FET) is located on top of a fully depleted wafer. A large area diode that functions as radiation entrance window covers the bottom surface. Depletion is achieved by reverse biasing the n-doped bulk contact with respect to the p-doped source, drain and back contacts. With suitable doping one creates a potential maximum below the channel of the transistor that we call internal gate. Signal electrons created anywhere within the depleted bulk assemble within this internal gate and increase the channel conductivity due to their induced mirror charges.

The charge can be removed completely from the internal gate by applying a positive voltage pulse to the clear (bulk) contact, thus restoring the previous situation. The charge can be measured

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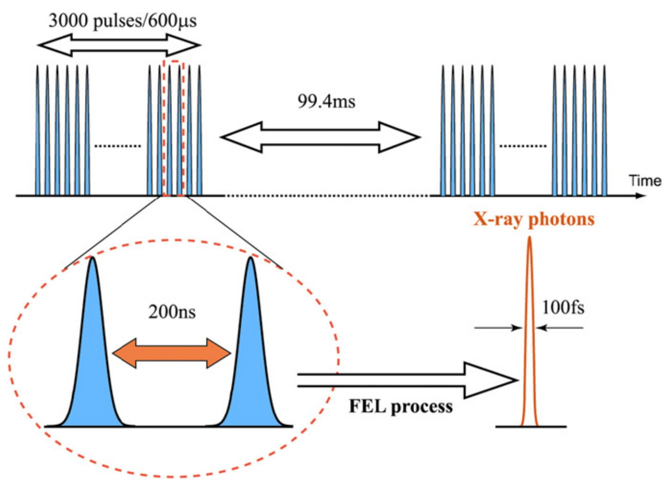

Fig. 1. Bunch structure of the XFEL: pulse trains with 3000 pulses of 100 fs length at a separation of 200 ns are followed by a gap of 99.4 ms.

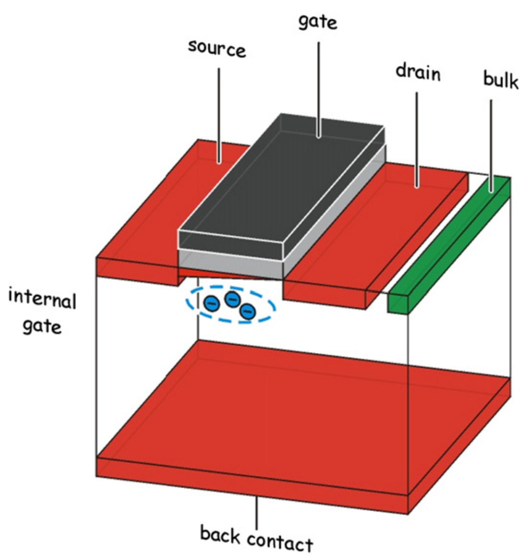

Fig. 2. DEPFET principle.

either by taking the current difference before and after charge collection or before and after clearing the internal gate.

A variety of DEPFETs have been invented with properties matched to the intended application. They include linear and closed geometries with several different clear mechanisms, MOS- and JFET versions, repeated readout devices with sub-electron noise [2] and gatable DEPFETs [3]. Here a recent non-linear device providing intrinsic signal compression will be presented.

3. The DEPFET sensor with signal compression (DSSC)

Although circular geometries are most natural a device with linear geometry (Fig. 3) has been chosen in order to explain the function principle. The DEPFET has a normal drain (D) and a very large area source (S). The internal gate providing the potential maximum below the transistor channel is provided by an n-type buried layer. Contrary to a standard DEPFET the internal gate is not constrained to the region below the channel (and external gate G), but extends far into the source (S) region. It is, however, formed in such a way that the region with highest potential (minimum for electrons) is located below the channel. Small signal charges therefore assemble below the channel while large charges will be distributed between channel and source region and only that part of charge below the channel is effective in increasing the DEPFET current. This way a strongly non-linear current-charge characteristic is obtained. The characteristic can be tuned by doping intensity and depth.

The top part of the figure shows also a clear structure as used for linear structures. Signal charge is removed sidewise from the internal gate (IG) across a clear gate (CLG) towards the clear contact (CL).

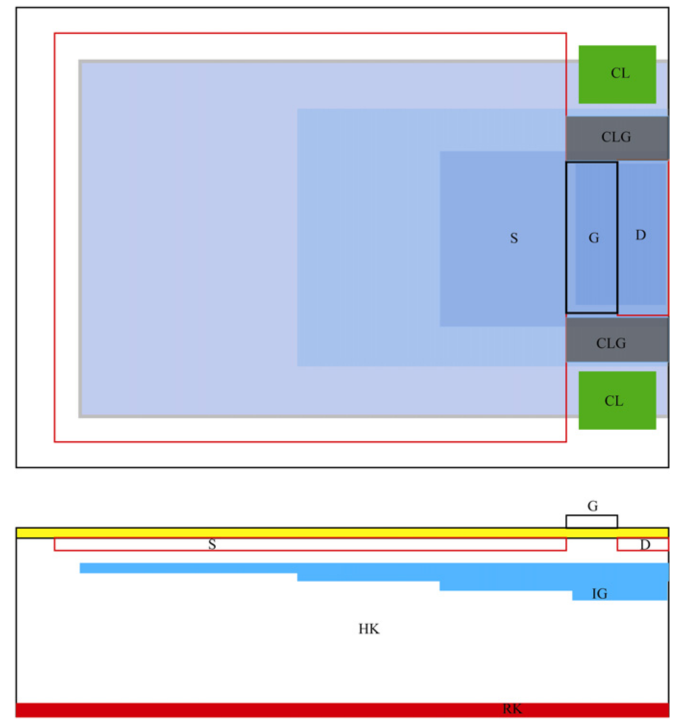

Fig. 3. DEPFET with intrinsic signal compression.

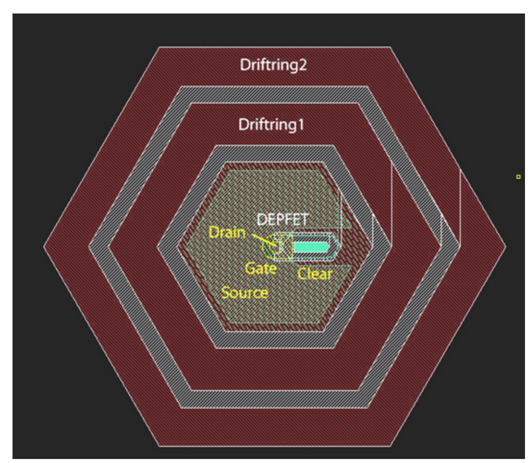

Fig. 4. XFEL DSSC pixel cell.

4. The DSSC pixel cell

A DEPFET with cylindrical geometry is located at the centre of the hexagonal pixel cell (Fig. 4). One arrives at this "quasi linear" DEPFET from the linear DEPFET of Fig. 3 by stretching and rotating