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Manufacturing uniform field silicon drift detector using double boron layer

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ABSTRACT

Novel SDDs with continuous junctions on both sides are fabricated using pure boron (PureB) depositions to create a shallow junction in the entrance window side and a continuous rectifying junction with different potentials as function of the drift coordinate in the device side. The SDDs made in this material offer lower leakage current. In addition, continuous SDD designed with two boron layers with different sheet resistances displays uniform electric field.

1. Introduction

Silicon Drift Detectors (SDDs) as proposed by Gatti and Rehak in 1983 [1–3] are X-ray detectors with a low output capacitance (in the order of 60fF), independent on the active area of the detector. This unique characteristic enables SDDs to have better energy resolution, high count rate and lower electronic noise at short shaping times which are well suitable for applications such as high resolution position-sensitive detection, fast ionizing particles and X-ray spectroscopy [3–5]. The amount of noise is dependent on the detector parameters such as leakage current and output capacitance and should be minimized in order to obtain better energy resolution [2]. The leakage current of a detector has three components: bulk generation current caused by thermal generation, diffusion leakage current caused by minority carrier's diffusion from un-depleted areas to the depletion region, and surface generation current caused by defects such as dangling bonds or scratches on the surface during processing. Surface leakage current increases with detector area and can surpass the bulk leakage current by a factor of 3–8 [9]. In order to lower the surface leakage current contribution, fabrication process steps on both sides of wafers have to be optimized to have damage free devices fabricated on front and backside of the wafers. Furthermore, thermally generated electrons at the Si–SiO_2 interface at the detector surface must be minimized by suitable design.

In some of the detectors a "sink anode" structure is used to provide a path to drain away the surface electrons through the p^+ field electrodes. The advantage of this structure is that the detector is less sensitive to radiation damage at the Si–SiO_2 interface too. However, in this type of detectors some part of the signal charges is being lost to the sink anodes [4,6–9].

In conventional circular silicon drift detectors, the p^+ junctions on the front (device) side of the detector are designed as concentric circular rings. Reverse bias is applied in such a way that an electric field parallel to the surface is created which forces the electrons to move towards the small sized collecting anode. On the back (entrance window) side of the device, a non-structured shallow implanted junction is made giving a homogeneous sensitivity over the whole detector area [10]. The back contact is kept at a constant negative potential to deplete the full thickness of the detector and creates an electric field component perpendicular to the detector surface [3,11]. In order to improve the low-energy detection capability of the detector the dead layer or non-sensitive area in the p^+ region of the entrance window should be minimized [12]. Since X-rays with lower energies have shorter attenuation length in silicon [13], detecting lower energies requires a shallow junction p–n diode.

This paper introduces two novel silicon drift detector structures (called continuous SDD and constant field SDD) using deposited nanometer thick pure boron layer. The boron layer acts as a distributed resistance for the electric field in the drift region as well as shallow p–n junction with a very low leakage current in the entrance window. When a voltage is applied to the rings it generates electric field which drifts the electrons toward the anode. Since there

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is no oxide layer present in the drift region, the leakage current will be lower. Moreover, a novel dual boron layer deposition technique will be introduced to maintain the electric field constant over the drift area resulting in fast collection of electrons. Another possible application of the thin boron layer can be as an ultra-shallow junction diode in the entrance window, to enhance the detection capability of the silicon drift detectors for soft X-rays [14].

2. PureB layer deposition

Extremely ultra-shallow junction diodes can be fabricated using boron layer deposition technology which can be used in the entrance window of the radiation detectors [14]. This layer has previously been implemented in photodiodes for the detection of radiation and charged particles with low penetration depth in silicon [14–17]. This technology is based on the chemical vapor deposition of pure boron layers to form the p^+ region using B_2H_6 gas at 700 °C. Depending on the deposition time and temperature the layer has a thickness of around 2–3 nm for detector applications and different sheet resistances ranging from 10^4 Ω/□ to 10^5 Ω/□ can be obtained [19]. The sheet resistance can be reduced to even lower values by annealing [18].

Fig. 1 shows a HRTEM (high-resolution transmission electron microscopy) cross-section view of the deposited amorphous boron layer on the Si wafer [15].

The resulting photodiodes surpass the performance of other existing technologies in internal quantum efficiency, dark current, uniformity and degradation of responsivity. At the same time they readily lend themselves to detector integration schemes that allow low parasitic resistance and capacitance [17].

3. Continuous silicon drift detector: design and simulation

3.1. Continuous SDD design

In silicon drift detectors, electrons are drifted toward the anode by p^+ voltage dividing rings. Existing oxide layers between p^+ rings increase the leakage current of the detector. In designing the drift region, low dark current and uniform voltage dividing capabilities are the important requirements. As mentioned in Section 1, p–n junctions fabricated by PureB (pure boron) layers offer very low leakage current. A 3D schematic of the layout of continuous silicon drift detector is shown in Fig. 2, where the anode is placed in the center of the detector and the drift region is a continuous-area with around 3 mm radius covered by the amorphous boron layer as distributed resistance. On the backside of the detector the active area is covered by a high performance shallow junction p^+ layer, PureB, acting as an entrance window. It is important to point out that the deposition of the boron layer on the drift side is different from that at the entrance window side. This allows obtaining a high sheet resistance diode at the drift side and a shallow junction diode at the entrance window [19]. A typical sheet resistance value for boron layer deposited at 500 °C for 20 min is 10^5 Ω/□ [19].

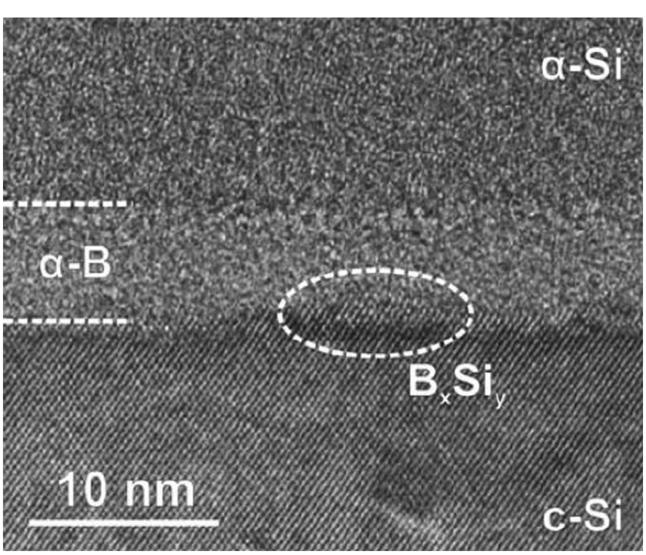

Fig. 1. High resolution TEM image of an amorphous-B layer formed after 10 min of B_2H_6 exposure at 700 °C [15].

3.2. Calculation of electric field in continuous design

In the continuous drift design concept, the resistance between the inner and outer contact pads is not uniform. It can be seen that the resistance of a ring-shaped area depends on the layer sheet resistance and the width and length of the ring (see Fig. 3a) as [20]:

$$R_{ij} = R_{sh}\frac{L}{2\pi r_g} \quad (\Omega) \tag{1}$$

where R_{sh} is the sheet resistance of the layer and L and $2\pi r_g$ are the length and the width of the ring, respectively as shown in Fig. 3a drawing.

In the continuous SDD structure, the drift region is a ring shaped resistor where we can calculate the resistance over the drift region from the above formula. As Fig. 3b shows for the same length the resistance near the anode,$R_A = R_{sh}(L/2\pi \times r_A)$, is much higher than the resistance in the outer part, $R_B = R_{sh}\ (L/2\pi \times r_B)$, of the drift region hence there is non-uniformity in the resistance distribution from the anode to the edge of the detector. The resistance of a continuous SDD calculated using the above formula drops significantly in the outer region as shown in Fig. 4 and the value of the resistance close to the inner ring is 30 times larger than that of the outer ring. For our layout with an inner and outer radius of 135 μm and 3135 μm, respectively and a boron layer with

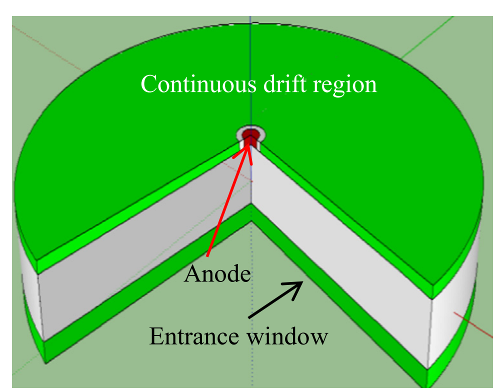

Fig. 2. Designed layout of continuous SDD using PureB layer

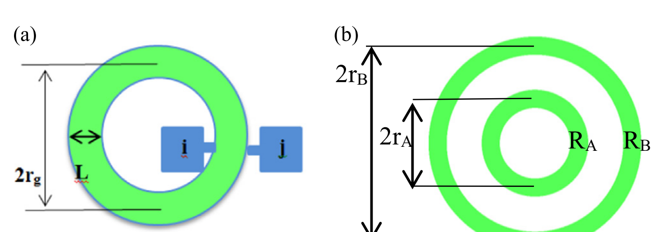

Fig. 3. Calculation of resistance of a ring shape structure