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Degradation study of single poly radiation sensors by monitoring charge trapping

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ABSTRACT

Special test structures emulating the performance of C-sensor, a direct floating gate (FG) ionizing radiation sensor, were used to investigate its degradation under Gamma radiation. Original MOS transistors with bulks made of crystalline silicon and Poly allowed minimizing the number of irradiations required to study the peculiarities of charge accumulation in the dielectrics of C-sensors. Electrical characterization of the developed structures before and after the exposure to different doses of Gamma radiation was performed. The guidelines for improving sensor immunity to radiation degradation are discussed.

1. Introduction

Sensing of ionizing radiation is required in medical, safety, homeland security, space/avionic and other applications.

Radiation detection by C-sensor [1] is based on the discharge of the floating gate (FG) due to interaction with the ionizing radiation. In addition to FG discharge, the high dose ionizing radiation degrades the device, in particular by charge built-up in the dielectrics surrounding the FG. Trapping of charge in dielectrics was shown to be the dominant degradation mechanism in the employed CMOS technology [2].In this paper we use the specially developed MOS structures for characterizing of the electric charge created by ionizing radiation, and present the results obtained for about 1000 test structures irradiated in different conditions.

2. C-sensor operation principle and degradation

In C-sensor, the single-Poly floating gate is coupled to CMOS inverter and two capacitors — tunneling and control (Fig. 1). Isolated P-wells in the silicon substrate under STI and GOX serve as the plates of the control and tunneling capacitors, respectively. The plates are isolated from the silicon bulk by regular and deep N-well implants.

The control capacitor has approximately 10 times higher value than all other capacitors in the sensor, so that about 90% of voltage applied to the control gate (CG) is transferred to the FG, in accordance with capacitive voltage divider operation. The discharge of the FG by the ionizing radiation occurs mainly in the region of the large control capacitor. CMOS inverter is utilized to allow digital read-out of sensor state (Fig. 2.a), represented by the mid-point voltage of inverter (Vm, also called Vt of sensor). Tunneling capacitor serves for Fowler–Nordheim (F–N) injection of charge into the floating gate. Charge injection is performed by applying high voltages (typically 6–7 V for 110 A gate oxide) of opposite polarities to control and tunneling gates. Since the control capacitor value is about 20 times larger than the tunneling capacitor, the applied voltage mainly drops on the tunneling capacitor dielectric, leading to F–N injection of charge from Si into the FG (Fig. 2.b).

In order to perform radiation sensing, C-sensor FG is charged with electrons. Exposure to ionizing radiation leads to the removal of electrons from the floating gate, proportionally to the absorbed dose [3]. Thus, by comparing Vt before and after the exposure, the absorbed dose is calculated (Fig. 3). The sensor response is calibrated using the standard dosimetry equipment.

The C-sensor FG is surrounded by relatively thick dielectrics: STI — 3000–3500 A; Si_3N_4 spacer — about 1000 A (Fig. 1.c). The ionizing radiation produces electric charge, which is trapped in these dielectrics [4,5]. This, in turn, influences various sensor parameters, like stability, repeatability, linearity, etc. For example, the hole charge,

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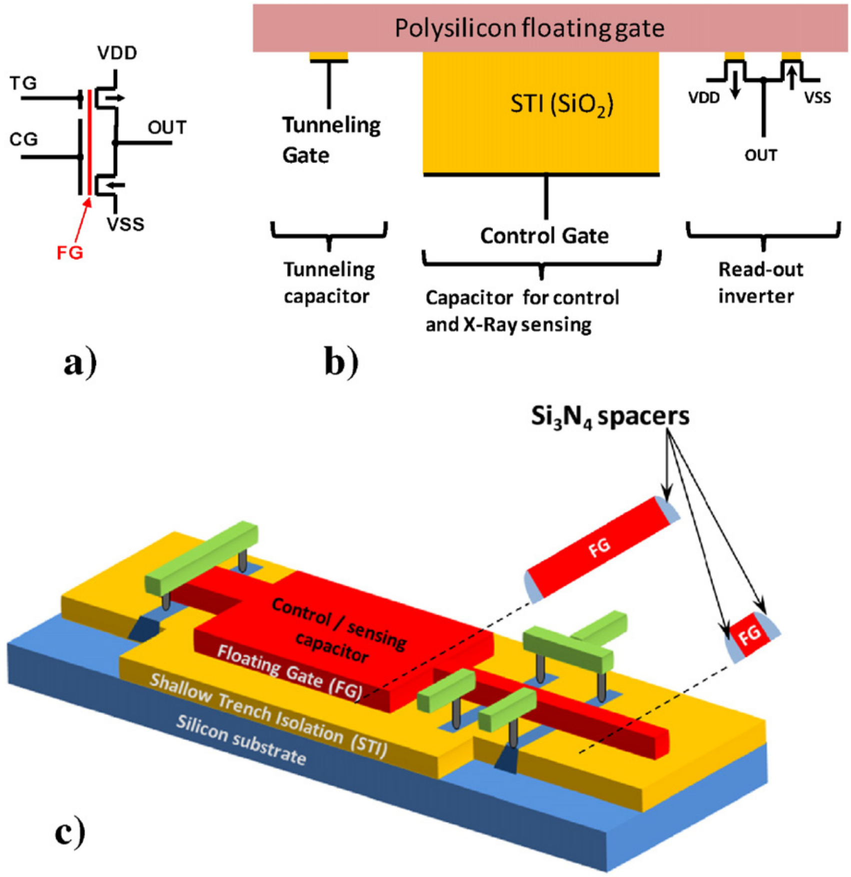

Fig. 1. The structure of C-sensor: a) electrical scheme; b) schematic cross-section; c) 3D structure view. Control capacitor area is 220 μm^2, tunneling capacitor area is 0.2 μm^2. Read-out transistors dimensions: NMOS W/L = 0.42 μm/0.6 μm, PMOS W/L = 0.42 μm/0.5 μm. Control capacitor oxide thickness is 3500 A, gate oxide in other components — 110 A.

trapped in the STI may de-trap [6] and influence the sensor readings (stability issue).

Comprehensive radiation experiments with the irradiated sensors are required to assess the device radiation immunity. This necessitates performing multiple irradiations and requires a lot of time and resources. In this paper we describe specially developed test structures with dielectric used to electrically isolate the FG and the results of their irradiation. The use of these structures allows performing the direct measurements of the electric charge generated by radiation and trapped in the insulators surrounding the FG.

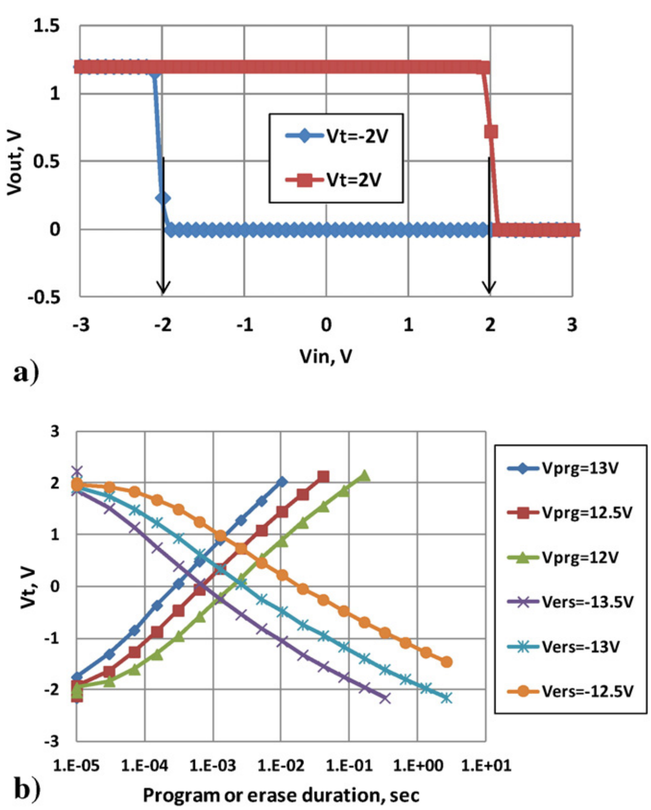

Fig. 2. C-sensor operation: a) Read-out curves; b) charging–discharging by F–N.

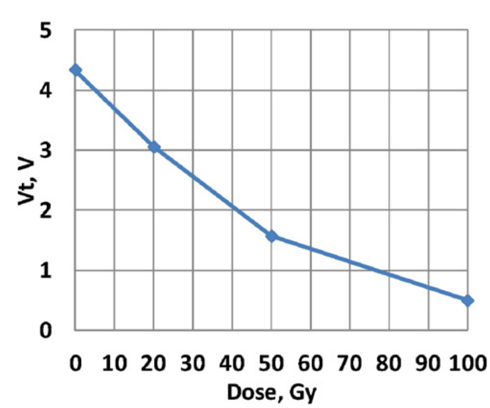

Fig. 3. C-sensor response to Gamma radiation (Co60).