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Assessing body built-in current sensors for detection of multiple transient faults

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ABSTRACT

Over the last few years, many architectures of body or bulk built-in current sensors (BBICSs) have been proposed to detect transient faults (TFs) in integrated circuits, all of them assessed through simulations in which only single TFs affect the circuit under run-time test. This work assesses and demonstrates the ability of a BBICS architecture in also detecting multiple and simultaneous TFs. Based on the classical double-exponential transient current model, multiple fault effects on a case-study circuit have been simulated with the injection of several current sources approximately representing the Gaussian distribution of a laser beam attack. Results show the BBICS architecture is able to detect multiple TFs simultaneously perturbing sensitive nodes of the case-study circuit.

1. Introduction

With the downscale of integrated systems, increasing their robustness against environment- or human-induced perturbations motivates considerable design challenges. Aging effects, alpha particles released by radioactive impurities, and more importantly, neutrons from cosmic rays are examples of environmental events [1]. In addition, fault injections to the end of retrieving secret data from security applications or disabling embedded secure protocols are human-produced attacks, which try to obtain fundamental information for cryptanalysis methods [2] or to activate hardware Trojans maliciously inserted in systems [3].

Radiation exposure and environmental variations are able to induce parasitic transient currents that may lead integrated circuits (ICs) to critical failures. Similar electrical effects are also caused by optical sources like flashlights or laser beams [4], which allow, moreover, finely controlling the injected current thanks to the high spatial and temporal resolutions of laser shots [5]. The induced transient faults (TFs) – i.e. temporarily voltage level modifications – are active only for a short duration of time, their occurrence are not predictable, and they may provoke soft errors (SEs) in stored results of system operations. Complementary, the generation of multiple TFs in nanometer technology designs is likely considering junctions are closer and single radiation-induced events may attain adjacent transistors [6]. If a laser irradiation is applied on advanced systems, the consequent injected TFs are indeed also multiple when the laser beam diameter covers several gates [4].

TFs need, therefore, to be detected at run time, and body (or bulk) built-in current sensors (BBICSs) are able to deal with TFs of short and long duration without impacting on the system operating frequency [7,8]. Furthermore, the monitoring is done close to the zones where the faults arise. Consequently, an early detection is possible immediately after a fault occurrence, preventing induction and propagation of errors to other clock cycles or system blocks. BBICSs combine the high detection effectiveness of costly fault-tolerance schemes (e.g. duplication with comparison) with the low area and power overheads of less effective mitigation techniques such as time redundancy approaches [8].

To the extent of our knowledge, this is the first work to assess and demonstrate by electrical-level simulations the BBICS ability in detecting multiple TFs arisen out either from laser irradiation or from natural radiation sources.

Section 2 recalls the background on the effects of laser illumination on ICs. Section 3 presents fundamentals about BBICS whereas Section 4 describes a simplified method for simulating multiple TFs induced by laser beams. Experiments demonstrating a BBICS detecting multiple TFs, and conclusions are discussed in Sections 5 and 6.

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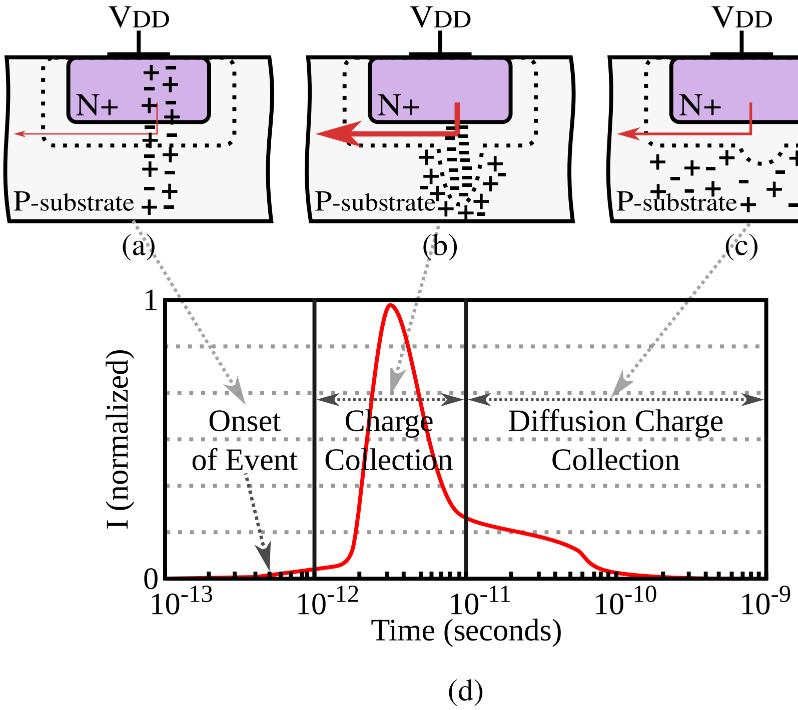

Fig. 1. Charge generation and collection phases in a reverse-biased PN junction and the resultant transient current caused by the passage of a laser beam [9,10]. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

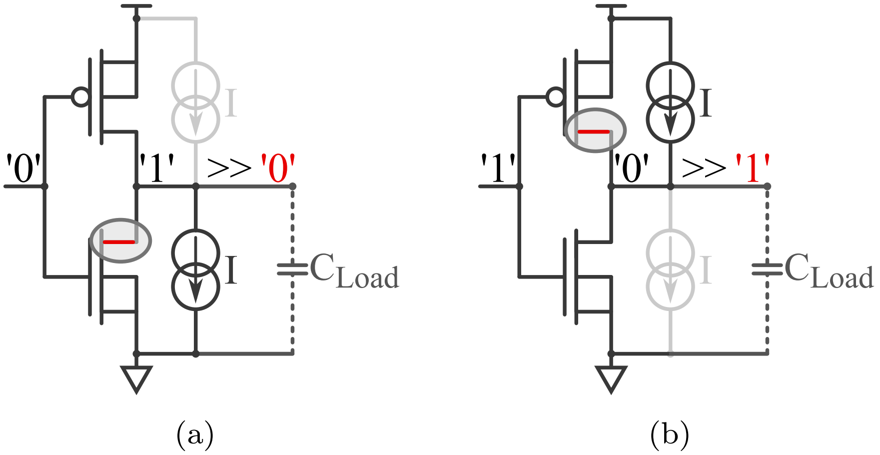

Fig. 2. Electrical model of laser-induced transient currents applied to a CMOS inverter. (a) NMOS sensitive drain. (b) PMOS sensitive drain.

2. State of the art of laser shot effects on ICs

2.1. Effect of a laser shot at transistor level

ICs are known to be sensitive to induced transient currents. Such currents may be caused by a laser beam passing through the device, creating electron-hole pairs along the path of the laser beam [9]. These induced charge carriers generally recombine without any significant effect, unless they reach the strong electric field found in the vicinity of reverse biased PN junctions (the reverse biased junction is the most laser-sensitive part of circuits) [10]. In this case, the electrical field puts these charges into motion and a transient current flows. Each induced transient current has its proper characteristics such as polarity, amplitude and duration that depend basically on the laser energy, the laser shot location, the device technology, the device supply voltage and the output load. The nature of these currents was first studied in the case of radioactive particles [11-15]. Laser illumination started then to be used as a way to emulate the effect of ionizing particles since the properties of the transient currents they both induce are similar.

Fig. 1 translates to the case of laser illumination the results of Ref. [10]. As shown in Fig. 1a, at the onset of an event caused by a laser shot, a track of electron hole pairs with high carrier concentration is formed along the path of the laser beam. When the resultant track traverses or comes close to the depletion region, carriers are rapidly collected by the electric field creating a current/voltage transient at that node. An interesting feature of the event is the distortion of the potential into a funnel shape [13,16]. This funnel enhances the efficiency of the drift collection by extending the field depletion region deeper into the substrate (Fig. 1b). The profile of the funnel (size and distortion) depends on the substrate doping. This collection phase is completed in the picosecond range and followed by a phase where diffusion begins to dominate the collection process (Fig. 1c). Additional charge is collected as electrons diffuse into the depletion region on a longer time scale (nanoseconds range) until all excess carriers have

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