Microelectronics Reliability 88–90 (2018) 476–481

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/microrel

Experimental characterization of critical high-electric field spots in power semiconductors by planar and scanning collimated alpha sources

Mauro Ciappa*, Ying Pang, Chenchen Sun

ETH Zurich, Integrated Systems Laboratory, Zurich, Switzerland

ARTICLE INFO

Keywords:
Power device reliability and robustness
Critical high carrier multiplication spots
Planar and collimated alpha source
Alpha source scanning

ABSTRACT

The occurrence of critical spots, where carriers' multiplication occurs due to the local high-electric field can be very detrimental for the robustness and the reliability of power devices, since catastrophic failure mechanisms like Single Event Burnout can be initiated at these locations. Traditional analytical techniques like DC analysis, photoemission microscopy, electron, and optical probing are not the first choice to detect the presence and in particular to locate such critical spots because they either lack in sensitivity, or they suffer from relevant penalties due to the thick metallization layers at the surface of the devices. In recent years, successful attempts have been made by finely focused high-energy ion beams. However, such nuclear probing techniques require advanced complex facilities like particle accelerators, operate under high vacuum conditions, and are not immune to radiation damage effects. In this paper, we propose the use of planar and collimated alpha sources to assess the presence and to locate critical high-field spots in power semiconductors. It is shown, that the proposed technique just requires basic spectrometry equipment and provides sufficient sensitivity and space resolution to fulfill all analytical requirements.

1. Problem definition

The occurrence of critical spots, where carriers' multiplication occurs due to the local high-electric field can be very detrimental for the robustness and the reliability of power devices, since catastrophic failure mechanisms, like Single Event Burnout can be initiated at these locations [1–3].

The detection of local charge multiplication through the measurement of the onset breakdown by DC techniques is normally very inaccurate. In fact, usually, carrier multiplication first occurs at small isolated spots (or lines), where the local current density may reach very high levels without reaching the current threshold that can be detected by DC measurements. Photoemission microscopy is very sensitive. However, its use is limited in power devices because the thick metallization layer can block the emitted photons. Alternative methods, which actively generate electron-hole pairs in the semiconductor by ionizing beams like electron and optical probing techniques (e.g. EBIC in SEM and front-side OBIC) cannot be used because of the limited range of the exciting signal.

In recent years [2, 4, 5], finely focused high-energy ion beams (IBIC) have been used successfully to delineate junctions and space charge regions, as well as to detect electric field enhancements in high power devices. Unfortunately, such nuclear micro-probing techniques require advanced complex facilities like particle accelerators, operate under high vacuum conditions, and are not immune to radiation damage effects.

In this paper, we propose the use of planar and collimated (exempt quantity) alpha sources as an alternative approach for ion beam induced charge microscopy. Special attention is paid to the detection of critical high-electric field spots in power semiconductors.

2. Experimental

Alpha sources (e.g. ^{241}Am, ^{210}Po, ^{232}Th) emit alpha particles in the 5 MeV to 6 MeV energy range. Alpha particles from non-collimated sources hit the surface of an exposed device under different impinging angles and exhibit a range in silicon up to 30 μm. Along their trajectories in the Silicon, alpha particles produce electron-hole pairs by direct ionization. In the depletion region of a PN-junction, electron-hole pairs are separated and a signal can be detected at the anode and cathode by a properly designed charge amplifier, which delivers a voltage peak, whose height is proportional to the deposited charge. Unlike in EBIC (or IBIC), the detector measures pulses arising from the interaction of single ions (pile-up suppression) and not a continuous current.

In case the maximum electric field in the depletion region

* Corresponding author.
E-mail address: ciappa@iis.ee.ethz.ch (M. Ciappa).

https://doi.org/10.1016/j.microrel.2018.07.129
Received 3 July 2018; Received in revised form 18 July 2018; Accepted 18 July 2018

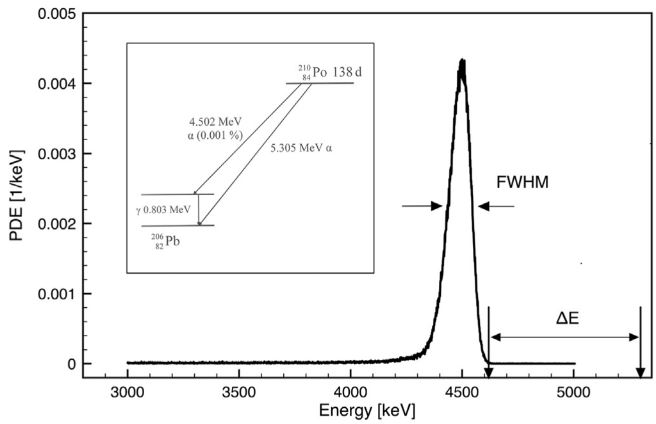

Fig. 1. Energy spectrum of the ^{210}Po planar alpha source, as measured with a Silicon detector. The peak shift ΔE = 700 keV is due to the absorption in 2.5 mm air (250 keV at dE/dx = 92 keV/mm) and in the 3 µm thick dead layer of the Silicon detector (450 keV at dE/dx = 144 keV/µm). The FWHM of the peak is 150 keV. The decay scheme of ^{210}Po in the insert shows that the main reaction channel is alpha emission at 5.305 MeV.

approaches the critical field (200 kV/cm in Silicon), electrons and holes are accelerated and gain sufficient energy to produce secondary electron-hole pairs by impact ionization. This effect results in a multiplication of the initial charge. For single events, the multiplication factor M is defined [6] based on the impact ionization coefficients (α_n and α_p for electrons and holes, respectively), as

$$1 - \frac{1}{M} = \int_\gamma \alpha_n(F)\, exp\left[\int_\gamma (\alpha_n(F) - \alpha_p(F))dx\right]dx$$

where F is the instantaneous field and γ is the trajectory of the carriers.

2.1. The alpha source

The alpha source used for present setup is Polonium 210 (^{210}Po). As shown in the insert of Fig. 1, ^{210}Po is an almost pure alpha emitter, with a main decay channel resulting in alpha particles at 5.305 MeV. A planar and a virtually point source have been used. In the planar source, with an activity of 0.1 µCi, a thin layer of the radioactive isotope is deposited on the top of an Aluminum slab mounted within a 2.5 mm deep recess in epoxy, with a total active surface of 12mm^2. In the point source, a thin layer of ^{210}Po is deposited at the top of a thin steel rod (0.7 mm diameter), resulting in a source activity of about 0.01 µCi (after collimation). The energy spectrum of the alpha particles emitted from the planar source are shown in Fig. 1, where the spectrum has been acquired by a dedicated semiconductor spectrometer. The peak is located at 4.600 MeV, i.e. 700 keV lower than expected. The observed shift is due to the energy loss of the alpha particles while crossing the 2.5 mm air layer (250 keV at a stopping power of 92 keV/mm [7]), and a 3 µm thick dead layer in the silicon detector (450 keV at a stopping power of 144 keV/µm [7]), i.e. before reaching the active layer of the detector. The FWHM of the peak as measured by the Silicon detector is 150 keV.

2.2. The spectroscopy chain

Two dedicated spectroscopy chains have been designed. The first, as shown in Fig. 2a, employs a trans-impedance amplifier (preamplifier) as the first stage to convert the current pulse produced by the device under test as a result of alpha particle ionization and carriers' multiplication (in the case of high electric field) into a voltage signal. A Sallen-Key second order active low-pass filter with pole-zero cancellation (pulse shaper) is added as the second stage to adapt the pulse bandwidth to the sampling rate of the analog to digital converter. The pulse, whose peak is proportional to the total charge detected, is then fed to a multichannel pulse height analyzer (MCPA) to build a histogram of frequency against the pulse amplitude.

In the second setup, shown in Fig. 2b, the trans-impedance amplifier and the pulse shaper are replaced by a resistive current-to-voltage converter coupled with a fast 14bit analog to digital converter. After digital conversion, the pulse is processed by a dedicated MATLAB application with the scope to check for the consistency of the pulse shape and to build a histogram of frequency against the pulse amplitude.

This detection chain is linear over a broad charge range and covers multiplication values M starting from 15 up to 25′000. Both configurations have been designed especially for power devices and can be operated up to 3.5 kV DC input voltage.

2.3. The collimator

In order to reduce the size of the beam spot at the surface of the target and to avoid excessive straggling of the beam energy, a collimator has been designed for the virtual point source. As shown in Fig. 3a, the collimator consists of a quartz capillary with 1 mm inner diameter and 1.2 mm outer diameter. The rod source can slide along the axis of the capillary, such that the distance from the bottom of the capillary can be finely adjusted to achieve the optimum trade-off between beam spot and the luminosity of the source. The optimum working point has been calculated based on the model in Fig. 3b and on the Monte Carlo simulation of Fig. 3c. For the following measurements, a 0.5 mm distance from bottom of the capillary and 0.5 mm flying height on the top of the sample have been used. This results in a 700 µm beam spot radius. Collimators with narrower beam spots in the 125 µm range can be easily manufactured, but at cost of the luminosity of the source.

The comparison of the beam energy spectrum in the non-collimated vs. the collimated point source, shown in Fig. 4a, clearly demonstrates that collimation reduces the energy straggling and also results in average in a larger range of the alpha particles in the Silicon target.

Range, stopping power, and linear charge deposition for alpha particles emitted by a ^{210}Po source and impinging on a Silicon device (2 µm SiO_2 passivation layer and 3 µm Aluminum metallization) under different angles have been calculated by Monte Carlo simulation and

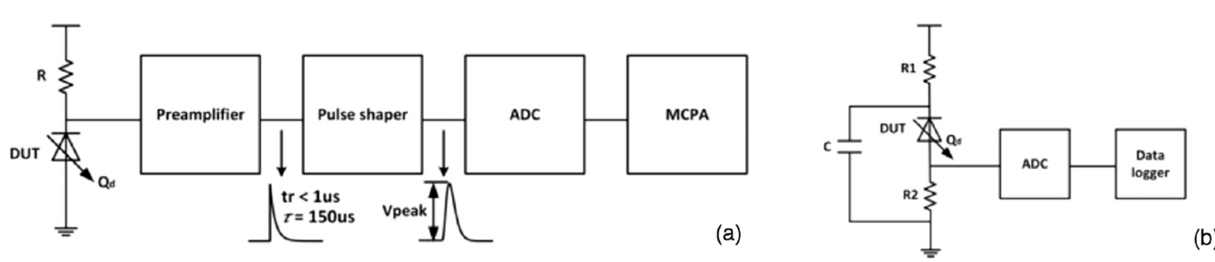

Fig. 2. (a) Block scheme of the spectroscopy chain used to measure the signal in the low multiplication range (M = 1–3) with 6fC resolution. (b) In the spectroscopy chain for pulses in the high multiplication regime (M = 15–25,000), the pre-amplifier and the pulse shaper have been by a resistive current-to-voltage converter. Both spectrometers are designed to operate up to 3.5 kV input voltage.