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Proximity gettering of slow diffuser contaminants in CMOS image sensors

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ABSTRACT

In complementary metal–oxide-semiconductor (CMOS) imager sensors, metallic contamination is a critical issue because it induces dark current and increases yield loss. Therefore, the challenge is to identify and eliminate progressively lower doses of metallic contamination. In recent years, Mo and W have received much attention because of their adverse effect on image sensor quality. This paper presents data from the testing of proximity gettering layers obtained by C or Si implantation, for what concerns their efficiency in Mo and W gettering. Deep-level transient spectroscopy (DLTS) was used to measure the impurity concentration in solid solution to evaluate gettering efficiency. Carbon implantation was found to be effective in capturing impurities, whereas Si implantation was not effective. Extended defects did not play a relevant role in gettering impurities, while gettering was found to be most effective in high impurity concentrations.

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Introduction

In recent years, CMOS image sensors (CISs) have received much attention for large-volume electronic applications such as mobile phones, digital cameras, webcams, and automobiles. CIS technology presents advantages over charge-coupled devices (CCDs) due to its lower power consumption and manufacturing cost; however, dark current in CISs is higher than that in CCDs [1]. As pixels are scaled down to 1.0 μm pitch, in order to maintain pixel performance the semiconductor industry is striving to improve sensor sensitivity, quantum efficiency, and other quality factors, while keeping dark current at lowest level. Dark current in image sensors is a parasitic current created by carriers that are not generated by photons in the photodiodes. The pixels in the tail of dark current distribution (Fig. 1) are called "hot pixels". It is enhanced by individual defects such as metallic contamination dissolved in Si, by interface states, or by structural defects; however, the main cause of dark current is the residual defects that are incorporated during the manufacturing process.

A dark current increase due to plasma processes and/or gate oxide integrity has been reported in literature [2]. Silicon/silicon dioxide (Si/SiO_2) interfaces in transfer gate or shallow trench isolation regions are known to be a dark current source that can be minimized by H passivation [3]. Metal contamination introduced by ion implantation is a potential source of contamination during sensor process fabrication [4,5]. Typical inline detection techniques are not sensitive enough to detect contamination levels that impact production yield; techniques such as deep-level transient spectroscopy (DLTS) or dark current spectroscopy (DCS) are required [6].

Metal contamination includes transition metals such as Fe and Cu, and metals such as Au, Mo, and W. Levels of less than $1 \cdot 10^8\ cm^{-2}$ are required for most transition metals. These metals have several properties that make them detrimental to imagers [7,8]. In fact, different metal contaminants form deep levels in the Si bandgap [10]. In depleted regions, they emit electrons to

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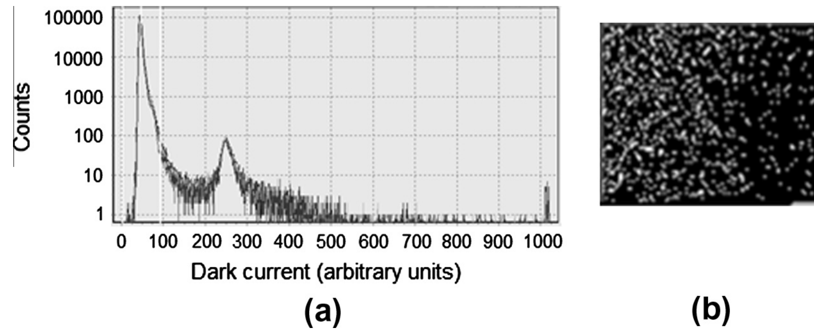

Fig. 1. Image sensor contaminated with Cu; (a) dark current histogram and (b) white spots indicating hot pixels.

the conduction band and holes to the valence band (Figs. 1 and 2). The main parameters that determine their electrical activity and generation rate are their activation energy E_t, their capture cross-section for electrons $\sigma_{n,}$ and their capture cross-section for holes σ_p. The Shockley–Read–Hall model for the generation rate of a deep level is used to calculate the dark current produced by a number of contaminant atoms [10].

Gettering techniques for fast diffuser contaminants (e.g., Fe, Cu, and Ni) are well established and include the so-called intrinsic gettering based on the gettering properties of bulk defects [11,12]; they also include various types of extrinsic gettering, such as gettering by heavy doping on the wafer backside or in the bulk of p/p^+ substrates [13], gettering by backside damage, or by polysilicon (poly-Si) deposition on the wafer backside [14,15]. These techniques are not effective for slow diffuser contaminants such as Mo and W because gettering sites are usually too far from the device regions [9]. These contaminants may be gettered only by a sort of "proximity gettering," such that the gettering regions are located at a shorter distance from the device than the metal diffusion length during thermal treatments involved in device processing. In addition, even if this condition is met, it is not clear if gettering would be effective for these metals. For example, Mo is reported not to be gettered at all, even in the region close to the gettering layer [16]. Also, Mo and W are reported to be very harmful to imaging devices, so effective gettering techniques would also be required for these elements [17,18].

Some cases of Mo contamination have been studied to identify the most sensitive techniques for this contaminant [17,19]. DLTS was found to be the most sensitive method for detecting Mo contamination in the Si volume. Due to the low Mo diffusivity, its diffusion is usually limited to a few microns from the Si surface, and this thickness corresponds to the region explored by DLTS. Conversely, in techniques based on carrier lifetime measurements, a much thicker region is usually probed (from a few 100 μm to the whole wafer thickness, depending on the specific technique). For this reason, these techniques are found to be less sensitive to contamination by slow diffusers than the DLTS technique. Long, high temperature treatments (e.g., 1100 °C for 2 h) are required to obtain some sensitivity of carrier lifetime measurements to Mo contamination. Under typical experimental conditions, the DLTS sensitivity is about 10^{10} cm^{-3}, and assuming that the Mo profile extends over a few microns, the sensitivity per unit area is in the order of 10^7 cm^{-2}, which is difficult to obtain, even by combining vapor phase decomposition (VPD) with a surface technique such as total reflection X-ray fluorescence (TXRF).

Implanted C has a very strong gettering effect for fast diffusers like Cu, Fe, and Au [20,21]. The implanted C forms strong gettering centers in Si, which are an order of magnitude more effective than implanted oxygen (another typical gettering element) [20]. A gettering efficiency dependence on the C dose was confirmed. No extended defects were seen after annealing for implant doses up to $2 \cdot 10^{16}$ cm^{-2} and energy of 3 MeV. However, the gettering of slow diffuser contaminants like Mo and W, with C implanted into Si has never been reported until the presentation of this paper.

On the other hand, residual crystal defects are usually found after the annealing of high dose implantations, and crystal defects are frequently reported to be able to getter metal impurities. To discriminate between the effect of residual crystal defects and of the implanted species, we chose a silicon implantation for an experiment to assess the ability of crystal defects in Mo and W gettering.

In this paper, we present data resulting from testing proximity gettering layers obtained by C or Si implantation for their efficiency in Mo and W gettering. Intentionally contaminated samples received implantation to form the gettering layer, and DLTS was used to measure the electrically active concentration in the Si volume. Gettering efficiency was estimated by comparing gettered wafers to not gettered wafers.

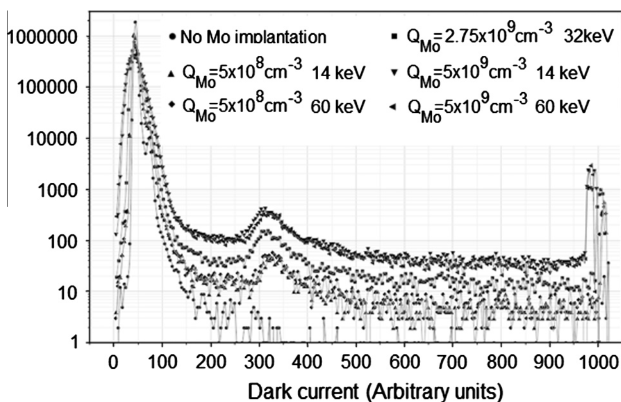

Fig. 2. Dark current histogram for pixels contaminated with different Mo implant doses/energy.

Experimental details

Wafers with the following characteristics were used in this study: (100) orientation; 200 mm diameter; and 725 thick wafers with a p− epitaxial layer grown on a p+ substrate. Deionized water solutions with 10 ppb, 100 ppb, and 1000 ppb Mo and W were prepared, and the wafers were contaminated by depositing 10 μl drops of a contaminated solution at five locations on the wafer surface (Fig. 3). The drops were then dried for 1 h at 90 °C. Some samples were used to measure the deposited contaminant amount per unit area by TXRF. The deposited contaminant was diffused into Si by a rapid thermal process (RTP) at 1100 °C for 3 min. Then, in some contaminated samples, a gettering layer was formed near

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