Low-Frequency-Noise-Based Oxide Trap Profiling in Replacement High-k/Metal-Gate pMOSFETs

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1. Introduction. There is currently a strong interest in the implementation of a replacement high-k/metal gate approach, offering a wider process window for the deposition of metal-oxide cap layers to tune the work function, and, hence the threshold voltage V_T [1,2]. One of the main concerns is to achieve a similar interface and oxide quality as for the standard gate first technology. Detailed studies have shown that both the interface state density, the low-field mobility and the reliability of the gate stack is largely preserved [1]. This was also confirmed by low-frequency (LF) noise measurements [3], which is a suitable tool for the study of near-interface border traps in the gate stack [4]. In fact, analyzing the frequency exponent γ of the $1/f^{\gamma}$ spectra enables to extract some information on the general nature of the border trap density profile in the high-k oxide. The aim of the present paper is to report on the LF noise and the corresponding trap density profiles of HKMG last pMOSFETs with an Equivalent Oxide Thickness (EOT) of ~1 nm. It is shown that for reference devices, the trap density increases with depth into the HfO_2, which confirms past results [5]. However, post-deposition exposure to a F-containing plasma etch changes the shape of the profile, evidencing the passivation of process-induced oxide traps by F [3,6].

2. Experimental conditions. The studied planar bulk pMOSFETs have been processed on 300 mm wafers, whereby the dummy gate is removed by HF etch. Next, a chemical interfacial oxide layer is grown in ozone, to create an SiO_2 interfacial layer (IL), followed by 36 cycles of HfO_2 by Atomic Layer Deposition (ALD). One wafer received a post-deposition 9 min SF_6 plasma exposure to introduce F in the gate stack. This was followed by a 1 min anneal in N_2 at 500 ^{o}C [6]. LF noise measurements have been performed as described earlier [3], on 1 μmx0.170 μm pMOSFETs (ΔL~35 nm) in linear operation (V_{DS}=-0.05 V) and with the gate stepped from weak to strong inversion. The frequency exponent is analyzed following the approach originally proposed by Çelik-Butler and Hsiang [7].

3. Results and discussion. It is shown that the LF noise spectra are predominantly $1/f^{\gamma}$-like (flicker noise), with a normalized Power Spectral Density (PSD) following correlated number fluctuations. In other words, the flicker noise is due to gate-oxide trapping. In line with previous results, it is found that exposure to the F plasma reduces both the average PSD and the sample-to-sample spread [3,6]. In order to further exploit the noise spectra, the frequency exponent has been derived versus the gate voltage. Based on the fact that $g=(\gamma-1)\alpha_t$, with α_t the tunneling attenuation factor of the electron wave function into the oxide, one can approximate the normalized oxide trap density profile by $N_{ot}(z)=N_{ot}(z=0)\ \exp(gz)$ [7]. Taking the value at V_{GS}~V_T yields the shape of the trap density profile at zero oxide field [4].

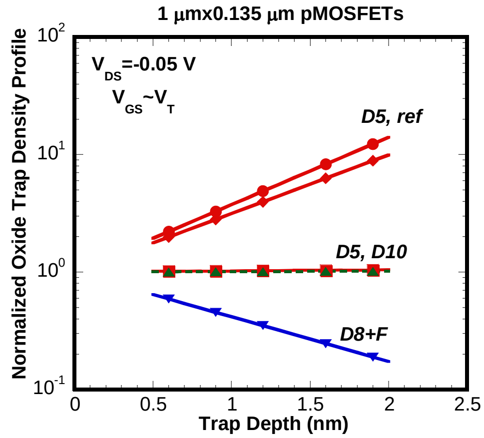

Fig. 1. Normalized trap density profile for two reference wafers (D5 and D10) and for a wafer, receiving a 9 min SF_6 plasma etching to introduce F atoms in the gate stack (D8).

A typical example is shown in Fig. 1, combining data for two reference wafers and a pMOSFET exposed to F. First of all, it is clear that there exists some device-to-device variability in the oxide trap density profile: while some references exhibit a strong increase of N_{ot} with depth, other devices show a more or less constant profile. This means that not only the trap density but also the depth distribution can contribute to the noise variability.

A second fact which is obvious from Fig. 1 is that the F-passivated pMOSFET has a trap density profile which decays with distance from the Si/IL interface. This gives evidence of the passivating effect of F in the gate dielectric, by in-diffusion from the gate. So, not only the total trap density is reduced but this occurs more efficiently further away from the interface.

4. Conclusions. It has been shown that the exposure of HKMG last pMOSFETs to a SF_6 plasma not only improves the LF noise by passivating a part of the oxide traps, at the same time, this passivation occurs more pronounced away from the interface. As a consequence, the frequency exponent of the flicker noise spectra changes from >1 for the references to <1 for the F-treated devices, at V_{GS}~V_T.

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