resistance to increase until that area is depleted causing the voids to coalesce which causes the local temperature and current density to drop and consequently the resistance drops.

A critical film temperature $T_c = 254\ ^\circ$C was identified at which the maximum height M of resistance transient reaches a peak value M_p as a function of current density. In addition, a new measurement technique of electromigration activation energy was also presented in this brief. It only requires measuring the height of the largest pulse detected during 160 s. This new technique does not require any averaging process. It uses only one sample for each activation energy and requires few minutes to obtain each data point.

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A Simple Technique to Measure Generation Lifetime in Partially Depleted SOI MOSFET's

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Abstract—**This brief presents a new, simple method of measuring the generation lifetime in silicon-on-insulator (SOI)MOSFET's. Lifetime is extracted from the transient characteristics of MOSFET subthreshold current. Using this technique, generation lifetime was mapped across finished Separation by IMplantation of OXygen (SIMOX) wafers and Bonded and Etchedback SOI (BESOI) wafers. BESOI material evaluated in this study had about seven times longer effective generation lifetime than SIMOX material and both the SIMOX and the BESOI are shown to have a lifetime variation of ±10% across four inch wafers.**

I. INTRODUCTION

Silicon-on-insulator (SOI) technology is becoming a promising candidate for future VLSI, as the quality of SOI material continues to improve. Carrier lifetime in SOI films is often used as a process-control measure because of its strong dependence on densities of crystal defects and heavy metal atoms. Carrier lifetime is also known to affect the performance of bipolar and CMOS devices. Several authors have reported generation lifetime measurement methods using SOI MOSFET's [1]–[6]. However, most of the techniques require complicated data analysis. The purpose of this paper is to propose a simple generation lifetime characterization method without numerical analysis.

II. ANALYSIS

A negative step voltage was applied to the gate of a partially depleted SOI MOSFET using HP4145B. The front gate voltage was stepped from 1.8 V (above threshold) to 0.4 V (subthreshold) with 0.1 V at the drain. Transient drain currents of MOSFET's are observed due to the floating-body nature of the device (Fig. 1) [7]–[10]. The drain current is suppressed immediately after the negative voltage step and it gradually increases to the steady state value with time. Since the negative voltage step makes the floating body potential negative during the transient, the body effect forces the “apparent” threshold voltage to increase, resulting in suppressed drain current. The drain current reaches the steady state value as the body potential relaxes back to zero as carriers are generated. The transient time T_0, which is defined as the time for the drain current to reach 90% of its steady-state value, is about seven times larger for the device on BESOI wafers than on SIMOX wafers.

During this transient, carriers are generated to replenish the space-charge region between the steady-state width of $x_{d\infty}$ and the maximum space-charge region width of $x_{d\max}$. The time rate of change of the space-charge region width x_d is given by [11], [12]

$$-qN_a\frac{dx_d}{dt} = q\frac{n_i}{\tau}[x_d(t) - x_{d\infty}] + qn_is \tag{1}$$

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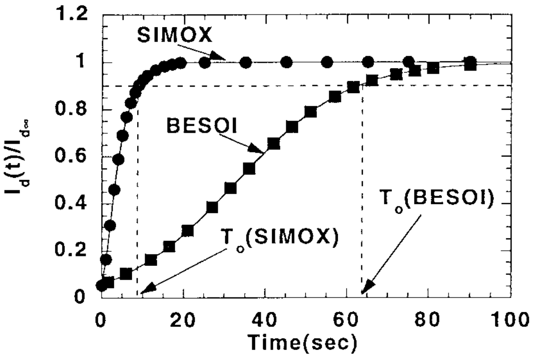


Fig. 1. Typical transient drain current characteristics for floating-body MOSFET's made on a SIMOX wafer and BESOI wafer. The drain current was normalized to the steady-state value of $I_{d\infty}$. T_0 (SIMOX) and T_0 (BESOI) represent the transient times of the MOSFET's on SIMOX wafer and BESOI wafer, respectively.

where N_a is the doping concentration, n_i is the intrinsic carrier concentration, τ is the effective generation lifetime, and s is the effective surface generation velocity. If we assume that the bulk generation in the space-charge region is dominant (it will be discussed later), (1) has the following solution:

$$x_d(t) = (x_{d\max} - x_{d\infty}) \exp\left(-\frac{n_i}{N_a}\frac{t}{\tau_g}\right) + x_{d\infty}. \tag{2}$$

The subthreshold current is proportional to $\exp\{\frac{q[V_g - V_t(t)]}{\xi(t)kT}\}$ where $V_t(t)$ is the time-dependent "apparent" threshold voltage, $\xi(t) = 1 + \frac{C_D(t)}{C_{\text{ox}}}$ and $C_D(t)$ and C_{ox} are the space-charge region capacitance and gate oxide capacitance, respectively [13]. The transient drain current normalized to the steady state current $I_{d\infty}$ is represented by

$$\frac{I_d(t)}{I_{d\infty}} = \frac{\exp\left\{\frac{q[V_g - V_t(t)]}{\xi(t)kT}\right\}}{\exp\left\{\frac{q[V_g - V_{t\infty}]}{\xi kT}\right\}} \tag{3}$$

where ξ is the $\xi(t)$ at steady-state. During the transient, the change in $\xi(t)$ is calculated to be less than 5%, which is much smaller than the change in $V_g - V_t(t)$ (which is about 150%), and therefore $\xi(t)$ was assumed to be constant in the following analysis. Then (3) becomes

$$\frac{I_d(t)}{I_{d\infty}} = \exp\left\{\frac{q\gamma[\sqrt{2\Phi_f} - \sqrt{2\Phi_f - V_{\text{BS}}(t)}]}{\xi kT}\right\} \tag{4}$$

where γ is the body effect coefficient and $V_{\text{BS}}(t) = -\frac{qN_a}{2\varepsilon_s}\{[x_d(t)]^2 - x_{d\infty}^2\}$. Fig. 2 shows the drain current calculated from (4) for different lifetimes. The measured current agrees well with the theoretical curve with 0.2 μs lifetime.

From (4) and (2), the relationship of τ_g to the transient time T_0 can be calculated:

$$\tau_g = \frac{\frac{n_i}{N_a}T_0}{\ln\left[\frac{x_{d\max} - x_{d\infty}}{\sqrt{x_{d\infty}^2 + \frac{2\varepsilon_s}{qN_a}\{[\sqrt{2\Phi_f} + 0.1\frac{\xi}{\gamma}\frac{kT}{q}]^2 - 2\Phi_f\}} - x_{d\infty}}\right]}. \tag{5}$$

The above equation is derived for uniform body doping case. For nonuniform body doping, the N_a term in (1) is not a constant and threrfore the rate of change in $x_d(t)$ and also the rate of change in $I_d(t)$ will depend on the doping profile inside the body, i.e., the rate of change in $I_d(t)$ is higher (lower) when the depletion edge during the transient is in the lower (higher) doping region.

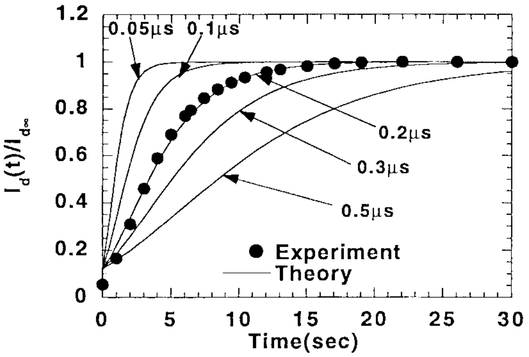
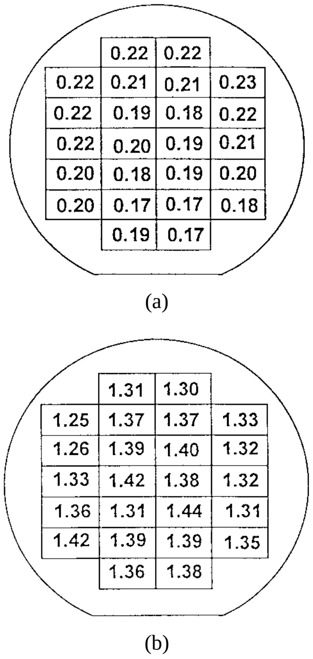


Fig. 2. Calculated transient drain current curves for various generation lifetimes. The measurement data for a SIMOX wafer are also shown. The measurement data match very well with the theoretical curve with 0.2 μs lifetime.



(a)

	0.22	0.22	
0.22	0.21	0.21	0.23
0.22	0.19	0.18	0.22
0.22	0.20	0.19	0.21
0.20	0.18	0.19	0.20
0.20	0.17	0.17	0.18
	0.19	0.17	

(b)

	1.31	1.30	
1.25	1.37	1.37	1.33
1.26	1.39	1.40	1.32
1.33	1.42	1.38	1.32
1.36	1.31	1.44	1.31
1.42	1.39	1.39	1.35
	1.36	1.38	

Fig. 3. Generation lifetime mapping obtained by our technique on (a) finished SIMOX wafer and (b) BESOI wafer. The data were obtained from one device per die. The unit of the lifetime is microseconds.

For the device with 105 Å gate oxide and 2.2 × 10^{17}/cm^3 body doping, (5) becomes

$$\tau_g = \frac{T_0}{45} \tag{6}$$

where the units of τ_g and T_0 are in microseconds and seconds, respectively.

III. RESULTS AND DISCUSSIONS

Equation (6) was used to characterize carrier generation in MOSFET's fabricated on different types of SOI substrates. Fig. 3 shows the measured lifetime across a SIMOX wafer and a BESOI wafer. A tight distribution of lifetimes across the wafer was observed. Since the two wafers were processed identically as part of a split lot, the difference in the lifetime comes from the quality difference of the initial SOI substrates.

We checked the validity of the earlier assumption that the generation in the gate space-charge region is dominant. The surface generation velocity was independently measured on gated-diode

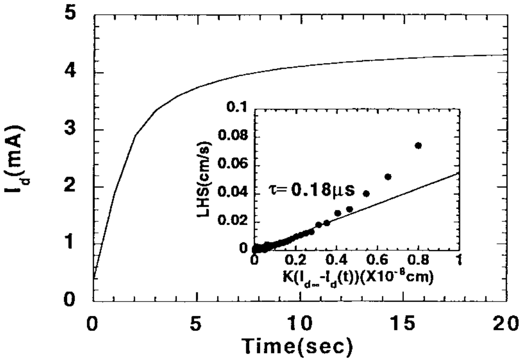


Fig. 4. Current transient and (inset) numerical analysis obtained by the method described by [1].

structures. The extracted surface generation velocity was about 3 cm/s for both SIMOX and BESOI wafers. Therefore, the contribution from the surface generation in the lifetime extraction is very small and is negligible for SIMOX wafer [Fig. 3(a)]. The surface contribution is no longer negligible for material with longer lifetime such as the BESOI wafer [Fig. 3(b)] and in this case the extracted lifetime should be interpreted as effective lifetime determined from both the bulk and the surface components. A large device with $W/L = 1000\ \mu$m/2 μm was used in the lifetime measurement to minimize the contribution from the generation in device isolation edge and in the source/drain-to-body junction. Short channel devices may not be good test structures for generation lifetime measurement since the generation in the source/drain-to-body junction space charge regions will dominate over generation in the gate space charge region. Therefore, the results from such devices should be interpreted with care.

In order to verify this lifetime measurement method, the lifetime was also measured with another technique previously published [1]. Fig. 4 shows the current transient and numerical analysis results. The lifetime extracted from the slope of the line in Fig. 4 was 0.18 μs, which is very close to the lifetime value of 0.20 μs obtained by our method. Since the front surface was inverted when we performed the technique of [1], the surface generation component was suppressed. The fact that the extracted lifetimes from the two techniques are almost the same even though the surface is depleted, during measurement with our technique, further confirms that the surface contribution is very small.

IV. CONCLUSION

In this paper, a new and simple technique for measuring generation lifetime in MOSFET's fabricated on SOI is presented. Transient subthreshold current is measured, from which τ_g can be determined easily without any numerical analysis. Its usefulness has been experimentally demonstrated and proven to provide very sensitive results as a function of different SOI materials. Lifetime mapping on SIMOX wafers and BESOI wafers shows a lifetime variation of ±10% across a 4-in wafer.

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