Pergamon

Microelectron. Reliab., Vol. 37, No. 10/11, pp. 1727–1730, 1997

0026–2714/97 $17.00 + 0.00

PII: S0026–2714(97)00149–2

A LASER BEAM METHOD FOR EVALUATION OF THERMAL TIME CONSTANT IN SMART POWER DEVICES

N. SELIGER[1], D. POGANY[1], C. FÜRBÖCK[1], P. HABAŠ[1], E. GORNIK[1] and M. STOISIEK[2]

[1]Institute for Solid State Electronics, TU Vienna, Floragasse 7, A-1040 Vienna, Austria
[2]Siemens Corporate Research and Development, Otto-Hahn-Ring 6, D-81730 Munich, Germany

Abstract: We present a non-invasive optical method based on infrared laser interferometry to study the thermal time constant in dielectrically isolated smart power devices. By analyzing the time domain optical reflectivity signal, the thermal time constant is determined independently of the applied heating power. Experimental values of the time constant are confirmed by calculations using equivalent thermal RC-networks.

INTRODUCTION

The combination of high-voltage power devices and low-voltage CMOS circuits in smart power ICs has become attractive in recent years. For bipolar devices like IGBTs with breakdown voltages exceeding 500V, dielectric device isolation using the 'Silicon-On-Insulator (SOI) by Direct Wafer Bonding' technique [1] is very promising as it is compatible to standard IC-processing lines. However, due to the buried oxide, self-heating effects in SOI-power devices are more pronounced than in bulk devices [2], which may influence the device characteristics in high power switching applications. The temperature in the device during the heating depends on the rate of the heat removal from the device. Knowledge of the thermal time constant is also important in circuit applications as the device characteristics depend on the temperature. In this contribution we present a non-invasive laser beam technique for the evaluation of the thermal time constant in SOI power devices operating under fast switching conditions.

EXPERIMENTAL TECHNIQUE

Devices used in this study are trench isolated Lateral Double-diffused (LD)MOSFETs and Lateral Insulated Gate Bipolar Transistors (LIGBTs) with different dimensions fabricated on wafer bonded SOI substrates [3]. The structure consists of a highly doped Si substrate of 600μm thickness, a 3μm buried SiO_2 layer, an active Si layer of 20μm thickness and a SiO_2 passivation layer (Figure 1). The temperature increase in the device is evaluated by monitoring the temperature-induced changes in the intensity of an infrared laser beam (λ=1.3μm, spot diameter 8μm) reflected from the $SiO_2/Si/SiO_2$-structure. The temperature increase causes an increase in the Si refractive index (thermo-optical effect) which causes an increase in the optical thickness of the silicon layer. This results in a variation of the reflectivity due to Fabry-Perot (F-P) interferences in this multilayer structure [4]. The device is optically accessed from the top side which has several advantages: Due to the high doping and large thickness of the substrate, the

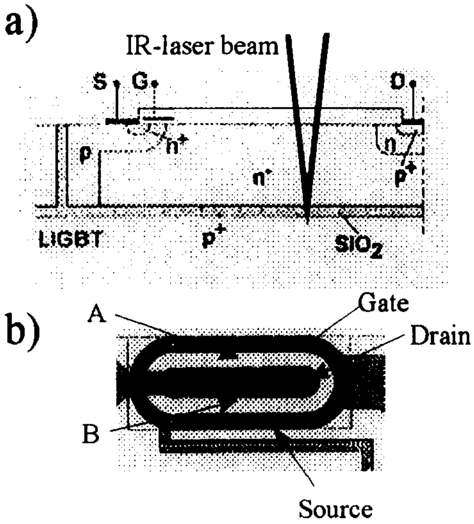

Figure 1 a) Cross section of LIGBT with the denoted position of the infrared laser beam. **b)** Top view of the device with laser beam measurement positions A and B indicated. The LDMOSFET structure is similar to LIGBT with exception of the p^+ region in the drain.

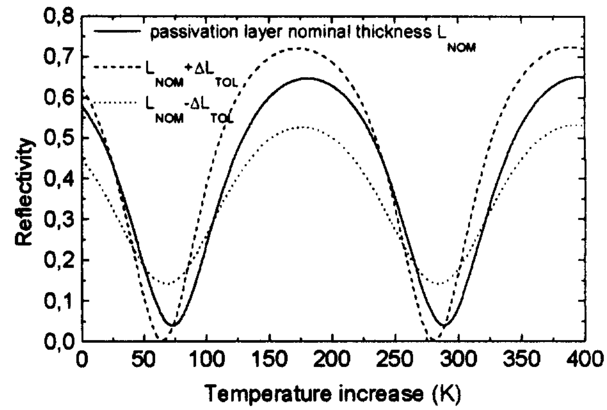

Figure 2 Calculated reflectivity of the $SiO_2/Si/SiO_2$-multilayer structure as a function of the temperature in the Si layer. The passivation layer thickness is varied within the technology tolerance limit ΔL_{TOL} ($dn/dT = 1.5 \cdot 10^{-4}\,K^{-1}$ [7]).

laser beam penetrating the buried oxide is absorbed in the substrate due to the free carrier absorption. Interferences due to temperature-induced changes in the optical thickness of the substrate are therefore not detected. As a consequence, the measured signal is only determined by the F-P interferences due to the temperature-induced changes in the optical thickness ΔL_{OPT} of the Si active layer. Assuming the temperature increase ΔT across the Si layer (in the beam direction) to be homogeneous, one obtains:

$$\Delta L_{OPT} = \frac{dn}{dT} \cdot \Delta T \cdot L, \qquad (1)$$

where dn/dT is the temperature coefficient of the Si refractive index, and L the thickness of the Si layer. The temperature homogeneity of the layer is justified for beam positions far from the channel region, which has been verified by electrothermal simulation [5]. The reflection coefficients of the Si layer F-P cavity are also determined by the thickness of the buried SiO_2 and the passivation layers. It should be emphasized that this optical method is non-invasive since no sample preparation is necessary and the laser beam does not influence the device characteristics [6]. Heating in the active layer was varied by applying gate pulses from 0 to 12V with 5 to 100μs length under various drain-to-source biases (shorted load conditions). Applied pulse period of 68ms has assured total device cooling between succeeding pulses.

RESULTS AND DISCUSSION

The time dependent measurements of the reflectivity were performed at different positions inside the devices. Since the thickness of the passivation layer may vary within a certain technology tolerance, the reflection coefficient of the top side of the Si F-P cavity may vary, too. To estimate the influence of this effect on the reflectivity, in Figure 2 we plotted the calculated dependence of the reflectivity on the temperature with the layer thickness as a parameter. It can be seen that for a small temperature increase in a region between intensity minimum and maximum, the intensity curve can be approximated by a linear function of temperature. Therefore, in this region the time constant of the temperature can directly be extracted from the time decay of the intensity. Figure 3 shows measured intensity signals obtained under low power conditions at different beam positions. The different absolute intensity and amplitude of the signals for different positions indicate small variations in the passivation layer thickness. During the heating, the intensity decreases almost linearly due to a nearly linear increase in the silicon well temperature. After heating turn-off, the decay of the intensity signal is directly related to the decay of the temperature. The cooling time constant from the exponential fit is found to be τ=40μs and τ=70μs for LIGBT and LDMOSFET, respectively.

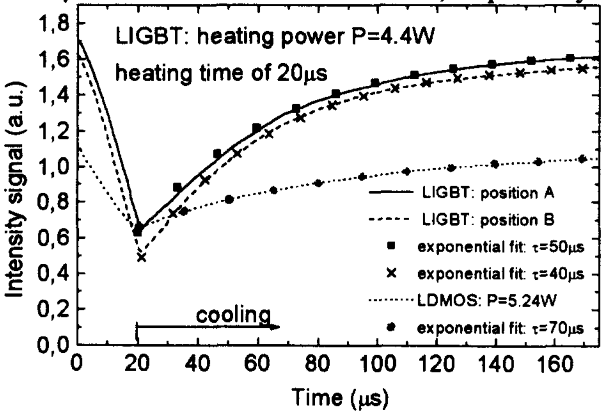

Figure 3 Intensity signal measured on position A and B (see Figure 1) in LIGBT and LDMOS transistors under small power conditions. The exponential fit is also indicated.

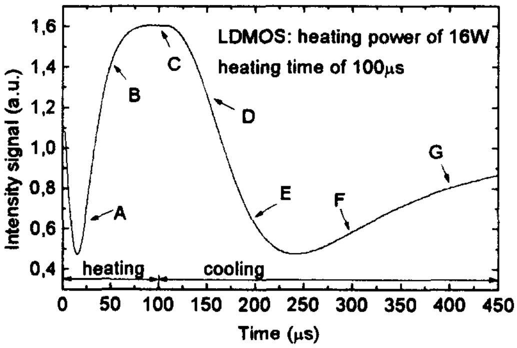

Figure 4 Intensity signal measured on LDMOSFET at high power dissipation and heating pulse duration of 100μs.

These time constants are close to the value of 50μs calculated for both devices from an equivalent thermal RC-network [8] considering the thermal resistances of the buried and trench oxides and the heat capacity of the silicon well. The different time constant of LIGBT compared to LDMOSFET found in the experiment is attributed to the different geometry (device length to width ratio) of these devices and therefore different lateral spread of heat across the isolation trenches. For the two particular devices used, however, this geometry effect is not taken into account in the thermal RC-network approximation.

Figure 4 shows a typical intensity signal evolution under high power conditions where multiple transitions between minima and maxima due to F-P interferences can be resolved. To obtain the cooling time constant in that case, we used the following procedure. First, we approximate the temperature increase ΔT during the heating by a quadratic function of time $\Delta T(t)=\alpha(t-\beta t^2)$, where α and β are constants. The coefficients α and β can be determined from the intensity-time curves using i) the symmetry of the F-P function relative to an extremum and ii) the known temperature difference ΔT between the closest minima and maxima taking into account the condition:

$$\frac{2\pi}{\lambda}\Delta L_{OPT}=\frac{\pi}{2} \tag{2}$$

Figure 5 shows the intensity evolution and a corresponding calculated temperature-time dependence. The coefficient α for the $\Delta T(t)$ curve evaluation was calculated using the value of $dn/dT=1.5\cdot10^{-4}K^{-1}$[7]. Figure 5 allows a unique determination of the temperature value from the intensity curve. This is used for the extraction of the temperature decay curve from the intensity variation after the heating turn-off. The temperature evolution during heating and cooling reconstructed from the intensity data in Figure 4 is shown in Figure 6. The value of τ=70μs obtained from an exponential fit during device cooling coincides well with the value obtained from experiments under low power condition (see Figure 3). An exponential fit with more than one time constants has shown that the term with the time constant of τ=70µs dominates and is significant for practical purposes. We would like to emphasize that assuming a different value of dn/dT [9] for the evaluation of the temperature increase may change the calculated absolute temperature value in the SOI layer (the peak temperature in Figure 6), but the evaluated thermal time constant remains unchanged.

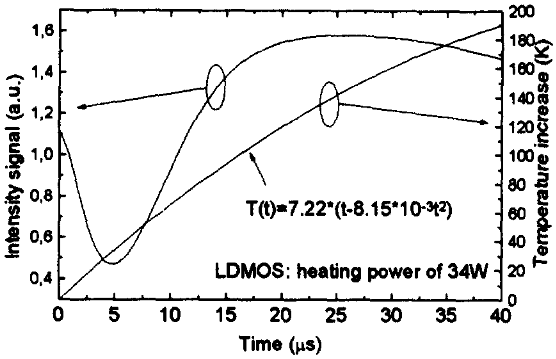

Figure 5 Optical intensity signal obtained from experiment at a very high power dissipation and the corresponding temperature function extracted from the optical data using a parabolic approximation.

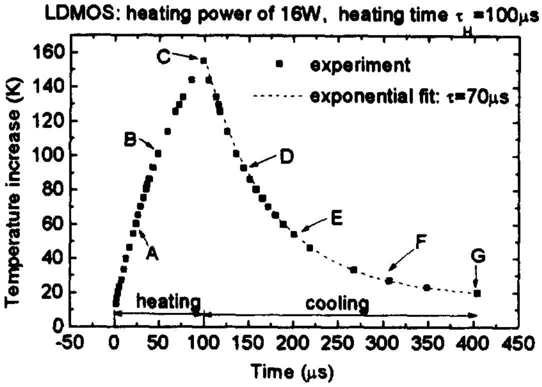

Figure 6 Evolution of the Si well temperature extracted from the measurement in Figure 4 and corresponding time positions A-G. Note that the sharp peaking of the temperature at time instant C originates from the fact that the temperature does not reach the steady state value for the heating time used.

CONCLUSION

The temperature induced change in the reflectivity of a multi-layer Fabry-Perot resonator structure inherent to SOI power devices is used to determine the thermal time constants of the device. The evaluation of the thermal time constant is found to depend neither on the optical properties of the F-P resonator nor on the temperature increase (power dissipation) in the device. Moreover, it is shown that the thermal time constant extracted form the F-P intensity curve is insensitive to the exact value of dn/dT for silicon.

ACKNOWLEDGMENT

This work is financially supported by the Austrian Federal Ministry of Science and the Society for Microelectronics, Austria.

References

1. W. P. Maszara, *J. Electrochem. Soc.* **138**, 341 (1991).
2. J. Korec, *Mat. Sc. and Eng.* **B29**, 1 (1995).
3. M. Stoisiek, K.-G. Oppermann, U. Schwalke and D. Takacs, *Proc. ISPSD'95*, 325 (1995).
4. M. Born and E. Wolf, *Principles of Optics*, pp. 323-329. Pergamon Press, New York (1985).
5. M. Stoisiek, unpublished results.
6. N. Seliger, P. Habaš and E. Gornik, *Microelectr. Eng.* **31**, 87 (1996).
7. H. Icenogle, B. Platt and W. Wolfe, *Applied Optics* **10**, 2348 (1976).
8. B. Tenbroek, W. Redman-White, M. Uren, M. Lee and M. Ward, *Proc. ESSDERC'93*, 189 (1993).
9. M. Bertolotti, V. Bogdanov, A. Ferrari, A. Jascow, N. Nazorova, A. Pikhtin, L. Schirone, *J. Opt. Soc. Am. B* 7, 918 (1990).