Optical crosstalk reduction in optically controlled microwave circuits on HR-Si using a trap-rich passivation layer

C. Roda Neve[1], D. Lederer[2] and J.-P. Raskin[1]

[1]Microwave Laboratory, Université catholique de Louvain

Place du Levant 3, B-1348 Louvain-la-Neuve, Belgium

[2]Tyndall National Institute, Lee Maltings, Prospect Row, Cork, Ireland

The reduction of Photo-Induced excess carriers of a coplanar waveguide photo-induced RF switch on High Resistivity Silicon substrate is presented. Experimental results from 40 MHz to 40 GHz demonstrate the important reduction of transmission line losses and optical crosstalk obtained by introducing a trap-rich passivation layer (Polysilicon and crystallized amorphous silicon) at the interface between the HR-Si and the field oxide. An optimal design for future photo-induced switches is proposed. By locally removing the passivation layer we can ensure the reduction of the interconnection line losses and optical crosstalk while maintaining an acceptable efficiency for the optical RF switch.

Introduction

Optical control of microwave circuits has proved its advantages against other control methods [1]: almost perfect isolation, immunity to electromagnetic interferences, less parasitic effects, fast response, higher bandwidth and integration. Such control is achieved by creating a photo-induced plasma zone at the illuminated area of a semiconductor substrate. However, the photo-induced excess carriers are not restricted to the illuminated zone, but spread within a larger zone (hundreds of µm) as a result of lateral carrier diffusion [2], [3]. Such zone can be large enough to influence neighbor devices and interconnections, by changing the semiconductor conduction characteristics. This effect, known also as optical crosstalk, has a strong impact on the performance of Monolithic Microwave Integrated Circuits that contain several optically controlled devices and also increases interconnections losses. Up to now this problem has been solved by spacing devices away from each other, thereby avoiding mutual influence from lateral carrier diffusion. However as downscaling and hybrid dense integration becomes a major trend for many applications, such design solutions will become inadequate and new technological solutions need to be found.

In parallel, high resistivity silicon substrates (HR-Si) have converted silicon into a suitable technology for high frequency applications [4] and hybrid integration [5]. However, as it is well known, oxidized HR-Si suffers from parasitic surface conduction effects (PSC) that increase RF losses at the substrate surface by creating a low resistivity layer at the SiO_2/Si interface [4]. PSC can be overcome by using a trap-rich passivation layer between the oxide and the HR-Si substrate, such as polysilicon (PolySi) [4] or crystallized amorphous silicon (α-Si) [6]. This technological solution can also be used to reduce the photo-induced excess carrier concentration in optically controlled devices and to stop lateral carrier diffusion. The unwanted diffused carriers are trapped into the passivation layer, allowing the control of the photo-induced plasma volume to the desired zones.

A simple optically controlled device, a photo-induced RF switch, is used to study the reduction of the photo-induced excess carriers for two different types of passivation layers: PolySi and α-Si. Optical crosstalk effects in adjacent devices and their reduction are also studied for this new technological solution. A new design solution, which maintains the efficiency of optically controlled devices while reducing optical crosstalk effects, is presented and characterized.

Photo-Induced Switch

We used a photo-induced switch to study the optical control of microwave circuits. It consists of a 1 µm-thick aluminum CPW of 871 µm length on top of a HR-Si oxidized wafer (5 kΩ-cm) with 50 nm-thickness SiO_2 layer. The dimensions of the CPW are W = 58 µm for the width of the central conductor, S = 36 µm for the slot width, and Wg = 208 µm for the width of the planar ground conductors. A CW laser diode source of λ = 671 nm was coupled into a 2 m length plastic optical fiber with a core diameter of 450 µm. The cleaved fibre output was placed over the CPW to obtain a 500 µm diameter spot light at the middle of the line, see inset in Fig. 1.a. In this setup, not all the light coming from the laser illuminates the substrate through the CPW slots. Assuming that the light intensity is homogenously distributed, only 18% of the light at the fibre output takes part in the photo-induced carrier generation. Hereafter we will use the effective optical power as the total amount of light that is injected inside the semiconductor.
The photo-induced attenuation from 40 MHz to 40 GHz, under various light power levels, is presented in Fig. 1.a. As expected, we observe that the efficiency of the photo-induced switch increases with the light power, reaching 35 dB attenuation at 20 GHz with 18 mW of optical power. The nature of the attenuation mechanism in our photo-induced switch is clearly reflective, see Fig. 1.b, as the return loss (S11) increases with illumination [7].

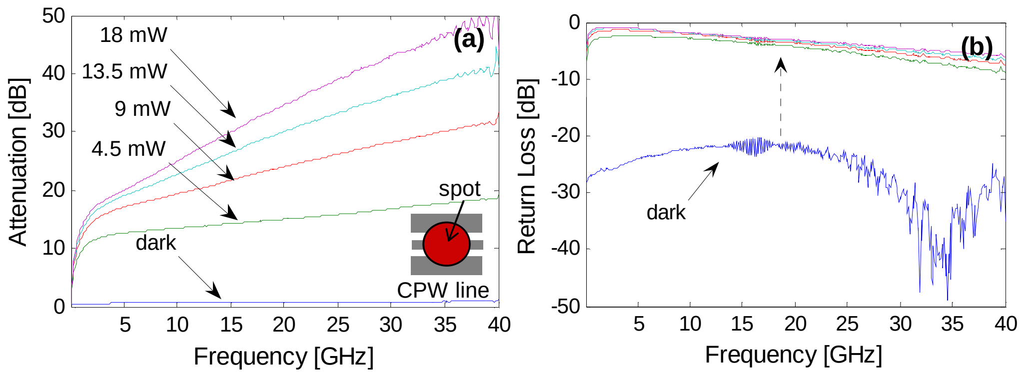

Fig. 1. Photo-induced attenuation (a) and return loss (b) of the optical RF switch on HR-Si under various effective illumination power levels.

Optical Crosstalk

To study the impact of optical crosstalk on the performance of neighbor devices we used the same setup as the one used for the photo-induced switch, but this time illuminating an area located besides the CPW, as illustrated in the inset of Fig. 2. We measured the attenuation of the CPW due to the optical crosstalk effect under various effective illumination power levels. As it can be seen in Fig. 2.a, the optical crosstalk totally degrades the performance of the CPW. We observe that for an effective optical power of 22.5 mW, similar to the operation point (35 dB of attenuation at 20 GHz) of our previous photo-induced switch, closer devices will be also attenuated by 10 dB due to optical crosstalk. Hence, for smaller devices and dense integration, as lateral carrier diffusion only depends on the amount of light and on the substrate properties, reduction of optical crosstalk effect becomes a matter of great importance.
To determine the optical crosstalk reduction when using a passivation layer below the oxide, we measured the impact of adjacent illumination for an identical CPW lying on a HR-Si with three different passivation layers: 178 nm-thick PolySi, 178 nm-thick α-Si, and 287 nm-thick α-Si. The attenuation for those three types of passivation layers is shown in Fig. 2.b for 90 mW of light. As it was expected, and in a similar way as free charges at the SiO_2/Si interface are trapped [6], photo-induced excess carriers are frozen inside the passivation layer, thereby not

contributing to the conductivity increment. Indeed, Fig 2.b shows that even for a high amount of light, 90 mW, the optical crosstalk is almost totally suppressed.

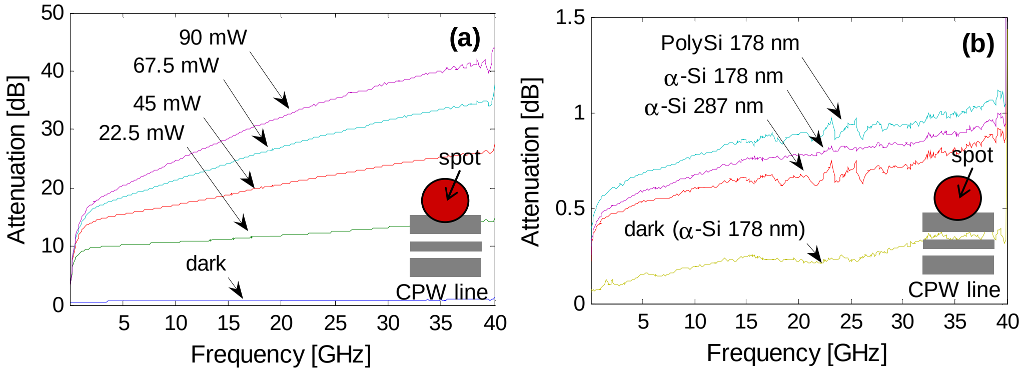

Fig. 2. Attenuation due to optical crosstalk for a CPW line on HR-Si (a) and on HR-Si with different passivation layers for 90 mW of effective optical power (b).

Photo-Induced Switch on HR-Si using a trap-rich passivation layer

Using a trap-rich passivation layer not only reduces optical crosstalk but also reduces the efficiency of any optically controlled microwave circuit lying on such type of substrate [8]. To maintain the efficiency of our optically controlled device, the passivation layer should be restricted to certain areas where the trapping of excess carriers is desired and where the diffusion of photo-induced excess carriers should be prevented. Thus we propose a new design for a photo-induced RF switch that consists of a CPW on top of a HR-Si substrate with a passivation layer in which a certain area is etched away, see Fig. 3.

To determine the efficiency of this new design, four types of substrates were fabricated. First, a reference wafer with an oxidized HR-Si substrate was used to obtain the efficiency of the original photo-induced switch. A second wafer with a passivation layer was used to verify the reduction of the photo-induced excess carriers and to determine the lowest photo-induced attenuation efficiency that can be reached. Another reference wafer with an oxidized HR-Si wafer was etched (TMAH etching) between the metallic patterns to measure the reduction in the photo-induced effect due to defaults at the SiO_2/Si interface related to the etching process. Finally a wafer with etched windows (TMAH etching) in the passivation layer was used to study the effect of different window sizes on the efficiency of the photo-induced switch.

The photo-induced attenuation of the four different wafers and for different window sizes is shown in Fig. 4.a and Fig. 4.b respectively. A CW diode laser of 7mW optical power and 660 nm wavelength was used to illuminate only one of the slots with a 10 μm diameter spot size. From the measured curves we can infer that the attenuation of the new photo-induced switch design is lower than expected. This is because the etching of the HR-Si substrate introduces defaults at the Si surface which act as traps for the photo-induced carriers. This is supported by the lower photo-induced attenuation observed on the etched HR-Si curve compared to the HR-Si curve in Fig. 4.a. The highest efficiency of the switch is therefore limited by that of the etched HR-Si. Regarding the efficiency for different window sizes we observe in Fig.4.b that increasing the size of the window increases the photo-induced attenuation, which demonstrates the confinement of the photo-induced excess carriers into a controlled plasma volume.

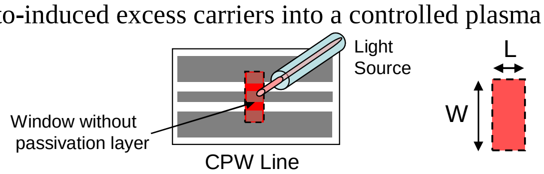

Fig. 3. New design of photo-induced switch on HR-Si with a trap-rich passivation layer.

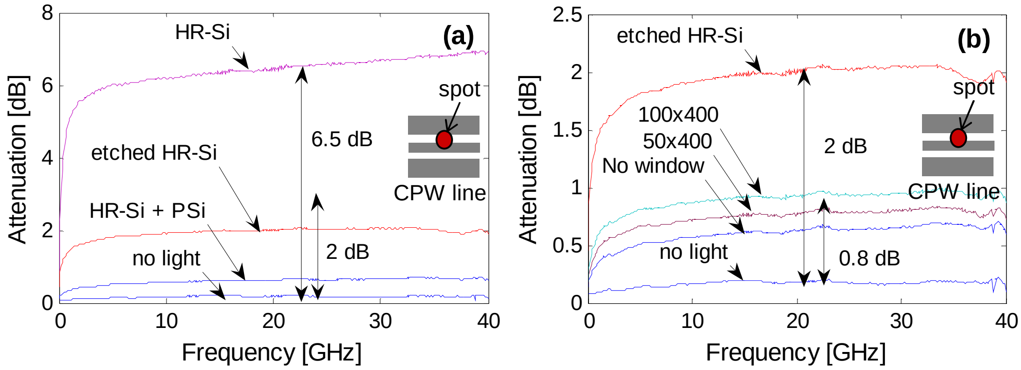

Fig. 4. Photo-Induced attenuation for different substrate types (a) and for different etched window sizes, LxW in µm (b).

Conclusion

We presented the high frequency characteristics of a photo-induced switch on HR-Si substrates. Degradation of the RF performance of neighbor devices due to optical crosstalk effect was also characterized, and the reduction of lateral carrier diffusion when using a trap-rich passivation layer was demonstrated. Combining HR-Si with a trap-rich passivation layer was proved to be an excellent solution to reduce the photo-induced excess carriers and to almost totally remove optical crosstalk effect. In addition a new design of a photo-induced switch that includes trap-rich passivation areas and increases the efficiency of the switch, compared to that lying on HR-Si with a passivation layer, was proposed and characterized.

Acknowledgement

This research work has been funded by the European Commission in the framework of the IP project PULLNANO.

References

[1] C.H. Lee, "Picosecond optics and microwave technology", IEEE Transactions on Microwave Theory and Techniques, vol. 38, no. 5, pp. 596-607, 1990.

[2] W. Platte, "Effective photoconductivity and plasma depth in optically quasi-CW controlled microwave switching devices", IEE Proc. J Optoelectronics, vol. 135, no. 3, pp. 251-254, 1998.

[3] G. Poesen et al, "Opto controlled substrate losses in a coplanar waveguide on HR-Si", IEEE MTT-S International Microwave Symposium Digest 2005, pp. 1401-1404, 2005.

[4] H.S. Gamble et al, "Low-loss CPW lines on surface stabilized high-resistivity silicon", IEEE Microwave and Guided Wave Letters, vol. 9, no. 10, pp. 395-397, 1999.

[5] D. Eggert et al, "A SOI-RF-CMOS technology on high resistivity SIMOX substrates for microwave applications to 5 GHz", IEEE Transactions on Electron Devices, vol. 44, no. 11, pp. 1981-1989, 1997.

[6] D. Lederer and J.-P. Raskin, “New substrate passivation method dedicated to high resistivity SOI wafer fabrication with increase substrate resistivity”, IEEE Electron Device Letters, vol. 26, no. 11, pp. 805-807, 2005.

[7] N. Weber, “New reflection-type optoelectronic microwave switch for CPW applications”, Electronics Letters, vol. 26, no. 7, pp. 455-456, 1990.

[8] C. Roda Neve, D. Lederer and J.-P. Raskin, “Optical Crosstal Reduction Using a HR-Si Substrate with Trap-Rich Passivation Layer”, European Microwave Conference EuMC 2007, 8-12 October, Munich, Germany, 2007.