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금이 보상된 실리콘 p-i-n 다이오드 스위치의 광 과도 특성

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Optical Transient Characteristics of Au-Compensated Silicon p-i-n Diode Switches

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Abstract

The optically-gated p-i-n diode switches have been fabricated with gold- compensated silicon. The turn-on and turn-off delay times and the rise and fall times were measured as a function of optical power level, bias, and pulse width. The turn-on characteristics shows a strong dependence an optical pulse power and a delay time(δt) between two pulses, but a weak dependence on the width of optical pulse. Actually there is no turn-off delay in gold-doped p-i-n switches and the fall time is negligible.

I. Introduction

There has been continued and increasing interest over the past decade in the areas of optically activated semiconductor switches for either high-speed or high power switching. A variety of materials have been examined for optically activated switches, including intrinsic Si, deep impurity-doped Si, Cr:GaAs, Cu:Si:GaAs, Fe:InP, CdS_xSe_{1-x}, and GaP.[1-10]

Various new types of optically activated semiconductor switches are developing, such as a bulk-type photoconductive switch, vertical or lateral p-i-n doides, an opto-GaAs MESFET, and an optothyristor.[2]

Photoconductive switches have been extensively studied, and recently junction switches have received much attention. Silicon p-i-n diode switches have been reported to deliver high electrical pulse power.[1-2]

This paper describes the experiments and the analysis on the transient characteristics of the optically-gated Au-doped silicon p-i-n diode switch. In particular, the turn-on and turn-off delay times and the rise and fall times were examined under various bias conditions, optical power levels and optical pulse widths.

II. Device Structure and Fabrication

The starting n-type silicon wafer has a resistivity of 10 Ω · cm. The anode was formed by p^+ diffusion using BN wafers as the source, and the cathode was formed by n^+ diffusion using $POCl_3$ as the source. Gold diffusion was then performed from the back of the wafer, using commercially available gold silica film on a source wafer. During the p^+ and n^+ diffusions, the back surface of the Si was protected by oxide, which was removed prior the gold diffusion. After gold diffusion, the resistivity of the sample was 50~80 kΩ · cm.

The device geometry is detailed in Fig. 1. The length of these devices is 5 mils and the size of the electrode is 1 × 10 $mils^2$.

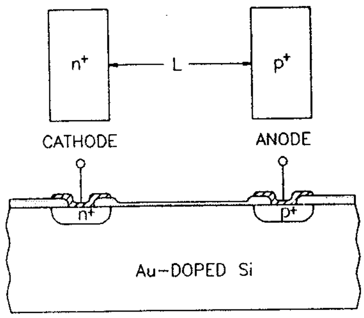

Fig.1 Optically-gate p-i-n switch

III. Optical Transient Switching Characteristics

The dark current(I)-voltage(V) characteristic obtainrd by a curve tracer is shown in Fig.2.

The main measurements of the optical transient switching characteristics were carried out using a double pulse generator with a variable delay time (δt) between two pulses. The first pulse was applied to a p-i-n switch device and second to a LED.

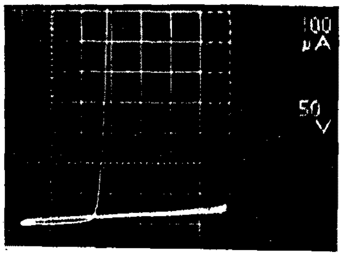

Fig.2 Dark currnt-voltage trace of optically-gated p-i-n switch

The relationship between the input, the light, and the output pulses is shown in Fig.3. The voltage pulse width was 10-11 μs and the light pulse width was changed from 1 μs to 8 μs. The light pulse trigger was also delayed about 0 to 7 μs after the initiation of the voltage pulse.

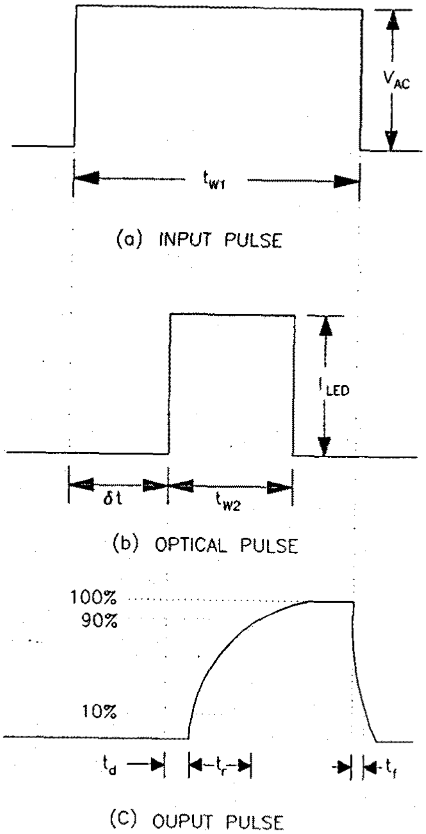

Fig.3 The relationship between the input pulse, the light pulse, and the output pulse

There is an inherent time delay in the turn-on process of p-i-n switches. Therefore, the output of the p-i-n device in response to an optical pulse of width t_{W2} is of the form shown in Fig.3(c), giving a clear picture of the relationship between the time constants related with the switching transient.

Figure 4 shows one example of an oscilloscope trace of transient switching for t_{W1}=10 μs input pulse. The turn-on delay time, the turn-on rise time, and the dwell time were estimated from these traces. These values were plotted as a function of light pulse power.

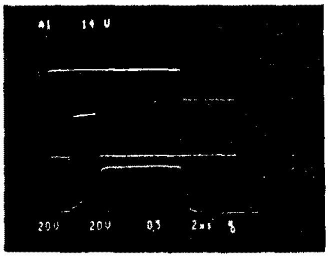

Fig.4 Oscilloscope traces of transient switching characteristics

III-1 Turn-on Characteristics

The turn-on time(or switching time) is characterized by a turn-on delay time(t_{don}) and a turn-on rise time(t_{ron}). The turn-on characteristics showed a strong dependence on a δt and a weak dependence on the width of optical pulse. First, the turn-on delay and rise times were investigated under various optical power levels and for δt=0, and then the effect of δt was measured.

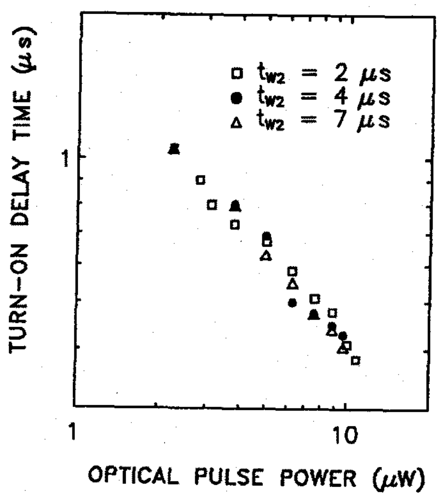

Fig.5 The deppendence of turn-on delay time on the optical pulse power.

The turn-on delay time is related to a minimum illumination because a certain number of gold acceptors must be filled with holes optically generated in the base region to turn on the device. Threrefore, with a given pulse, the delay time will decrease as the optical power increases.

The dependence of the measured turn-on delay time and turn-on rise time on optical pulse power is shown in Fig.5. As expected above, the delay time decreases with increasing optical pulse power.

Figure 6 shows the variation of rise time with optical pulse power.

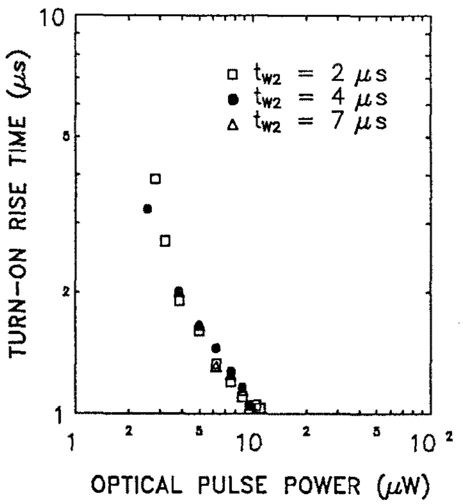

Fig.6 Turn-On rise time vs. optical pulse power

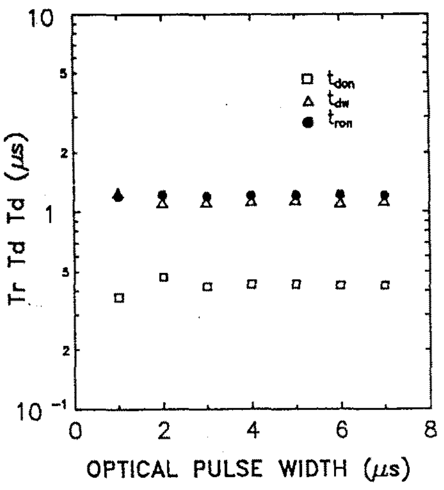

Fig.7 The deppendence of turn-on charateristics on the pulse width for different optical pulse power

As shown in Fig.7, the turn-on characteristics depend weakly on the width of optical pulse under the experimental conditions(1~8μs).

However, the switching characteristics depend strongly on the location δt of the optical pulse V_L, as shown in the Fig.8, where δt varies, while V_{AC}, V_L and t_{w1} are fixed. As δt increases, the switching disappears. The critical δt, at which the device is turned off, depends on the optical power level and the optical pulse width.

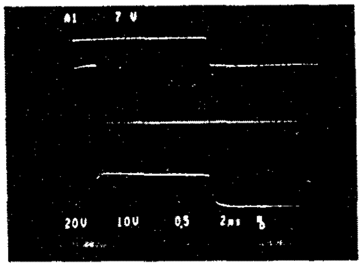

Fig.8 Oscilloscope traces showing the effect of δt on the turn-on characteristics

Figure 9 shows the critical δt as a function of optical pulse width for different values of optical power. For fixed optical power, the critical δt increases when the width of optical pulse increases. For a fixed optical pulse width, the critical δt increases with increasing optical power. This allows us to determine the width t_{w2} and location δt of the optical pulse tp turn on the devices. As an example, for an optical power of 5 μW with width of 2 μs, δt should be less than 1.5 μs in order for the device to turn on. If an optical pulse of 6.26 μW and 4 μs is used as a optical source, the device switchs even at δt=8μs.

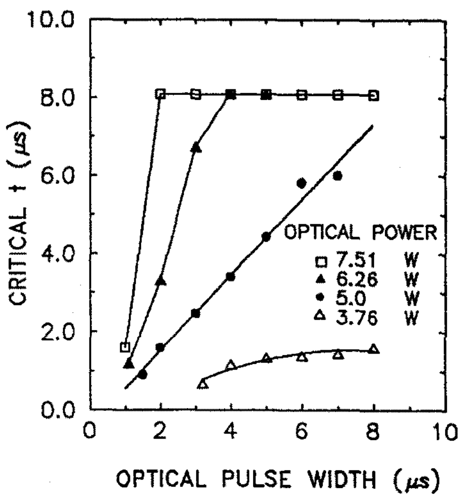

Fig.9 Critical δt vs. optical pulse width

III-2 Turn-off characteristic

The turn-off transient is of great practical importance in switching applications. Generally, the turn-off time is characterised by a turn-off delay time and a fall time. As shown in Figs. 4 and 8, actually there is no turn-off delay in gold-doped p-i-n devices and the fall time is negligible. These results are very different to p-n junction switches like SCRs, which have a long delay time. This is because the turn-off process is governed by the recombination of non-equilibrium carriers through the gold acceptor level in the base region of p-i-n device.

IV. Conclusions

In this paper, we have presented the optical transient characteristics of gold-doped silicon p-i-n switches. The turn-on and turn-off delay times and the rise and fall times were examined under various bias conditions, optical power levels and optical pulse widths. The optical turn-on characteristics showed a strong dependence on the optical pulse power and width. The delay and rise times decreased with increasing optical power level. The switching behavior also depended strongly on the time delay between the leading edges of the input pulse and optical pulse. The turn-off transient measurement showed that the turn-off delay and fall times are negligible. These results show the possibility of optically-gated p-i-n devices as fast power switches, compared to SCRs, which have a long delay time.

Refereces

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