# An optically controlled SiC lateral power transistor based on SiC/SiCGe superjunction structure*

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**Abstract:** An optically controlled SiC/SiCGe lateral power transistor based on superjunction structure has been proposed, in which n-SiCGe/p-SiC superjunction structure is employed to improve device figure of merit. Performance of the novel optically controlled power transistor was simulated using Silvaco Atlas tools, which has shown that the device has a very good response to the visible light and the near infrared light. The optoelectronic responsivities of the device at 0.5 $\mu$m and 0.7 $\mu$m are 330 mA/W and 76.2 mA/W at 2 V based voltage, respectively.

**Key words:** SiC/SiCGe; superjunction; optically controlled transistor
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## 1. Introduction

With electronic products wide applications, electromagnetic interference (EMI) effect is a critical issue for safety and reliability in power electronic systems. Photoelectric isolation method is an effective way to resolve electromagnetic interference problems[1]. Although the Si-based light control transistor has been developed for many years, its physical properties make it difficult to use in high temperature, high frequency and high power applications. With silicon carbide (SiC) wafer localization and mature of high quality 6H-SiC and 4H-SiC epitaxial technology, SiC power devices set off an upsurge study.

However, SiC is not optically active near IR wavelength range where light sources are readily available for optical communication. In order to realize light-activation of SiC power switching devices, a hybrid approach that combines a silicon photo-receiver module with a SiC power Darlington transistor has been proposed[2]. In this hybrid Si/SiC device, the Darlington transistor is activated by photocurrent output from an individual Si photodiode. Therefore, the EMI problem may still exist because the direct input of the Darlington is actually an electronic signal. To prevent the EMI problem absolutely, we proposed a light-activated SiC Darlington transistor in an earlier work[3], in which by using narrow bandgap material SiCGe as a base layer, the device can realize light-activated power switches for a common light source.

In this paper, we propose a novel optically controlled SiC power transistor structure based on the SiC/SiCGe superjunction to improve the light sensitivity of the device. Employing a two-dimensional device simulator Silvaco Atlas, we have simulated the performance of this device based on 4H-SiC and $SiC_{0.8}Ge_{0.2}$.

## 2. Device structure

As shown in Fig. 1, the device has a lateral structure with two electrodes—Ta and Tb, and characterized by a vertical $P^+$-SiC column that extends all the way to the p-type, SiC layer. The bottom p-SiC layer acts as the charge-compensating layer that makes the electric field distribution in the device two-dimensional, the doping and thickness values of this layer have been designed to realize the superjunction charge-balance[4], i.e., the total positive charge contributed by p-SiC layer equals the total negative charge contributed by the top n-SiCGe layers, otherwise device performance decreases rapidly. With the interactive of vertical and parallel pn junction, the rectangular electric field distribution is formed, compared with convention triangular electric field distribution, device sensitive and responsivity increase a lot. In the blocking or open state, the applied voltage is supported by the reverse biased pn junction between the p-body and n-drift regions. When the triggering beam falls on the device, SiCGe layer absorbed it and generates electron–hole pairs by photogeneration. They are mobilized by the local electric field and attracted by the two electrodes via a conducting channel. If the light beam is sustained the conductivity is sustained. However, when the light shuts off, the carriers are recombined among themselves and the switch goes back to its high-resistivity blocking state.

## 3. Simulation results and analysis

In order to achieve the realistic results, several important material parameters used in the Silvaco Atlas were adjusted to obtain the closest agreement with published material data of

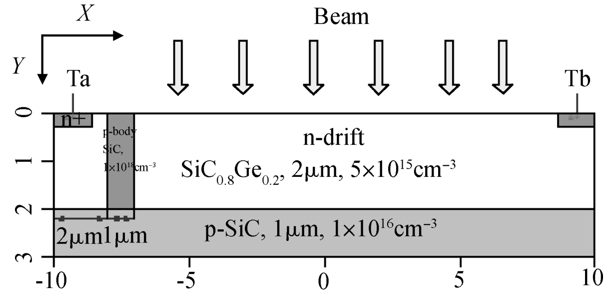


Fig. 1. Structural schematic of the device.

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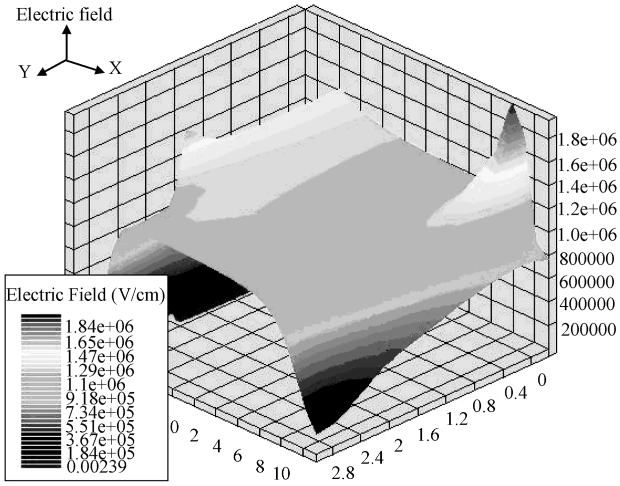


Fig. 2. Electric field distribution at block-state.

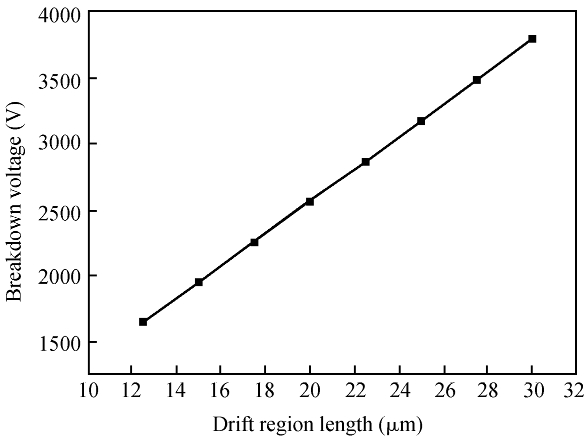


Fig. 3. Linear relationships with drift region and breakdown voltage.

4H-SiC. For example, the energy band gap at room temperature was adjusted to 3.26 eV. Also, models used in the simulator are bandgap-narrowing effect, impact ionization, Auger recombination, SRH recombination, Fermi–Dirac statistics and incomplete ionization of impurities.

Since SiCGe is still at an early stage of study, the material parameters are considered as the same as SiC except bandgap, absorption coefficient and ionization coefficient. The bandgap of SiCGe depends on the mole fractions of the alloy. Here, consider that SiCGe ternary is composed of SiC and Ge for simplicity. The calculations in our research showed that with Ge ratios of 0.1, 0.2, 0.3, 0.4, and 0.5, the corresponding band-gap values are 1.82, 1.67, 1.52, 1.38, and 1.24 eV. According to the McFarlane-Roberts equation for indirect bandgap semiconductors[5], the absorption edge of this ternary semiconductor can cover a wide range of the near-infrared. Assume the ionization coefficient has the linear relationship with Ge ratio. For simulation of the light-activated device, consider the response to either the visible or the infra-red light and the lattice match to SiC, which have a contrary requirement for the content Ge ratio of the SiCGe alloys. $x = 0.2$ is used for $SiC_{1-x}Ge_x$.

Figure 2 shows two-dimensional electric field distribution in the drift region at the instant of breakdown when superjunction charge-balance condition is satisfied. The electric field is two-dimensional and almost uniformly across the drift region, because there is no further variation on the charge distribution and charges compensate each other in the drift layer. With a more uniform electric field distribution along the drift region, breakdown voltage depends only on drift region length and does not depend on doping concentration. The simulation result demonstrates that the blocking voltage becomes a linear function of the drift region which is shown in Fig. 3.

A plot of photocurrent versus incident light intensity under 2 V biased is shown in Fig. 4. The wavelength of incident light is 0.5 $\mu$m. It indicates that the photocurrent is linear function of the incident light intensity. The slope of the plot, i.e. the optoelectronic responsivity, is 330 mA/W.

Fix incident light intensity of 1 W/cm$^2$ for different wave-

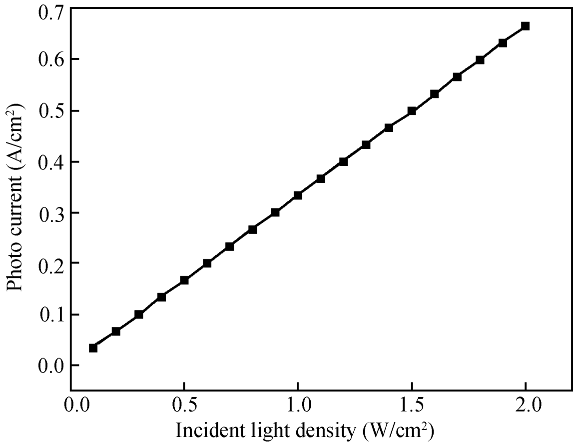


Fig. 4. Photocurrent versus incident light intensity.

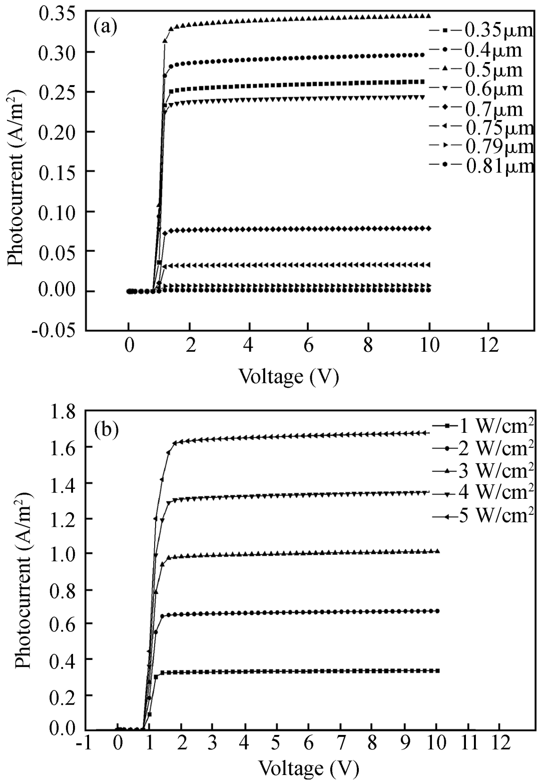


Fig. 5. $I$–$V$ characteristic curve of the device.

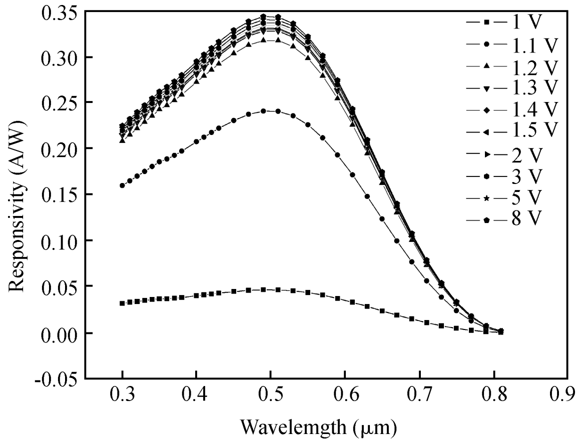


Fig. 6. Response spectra at different biased voltages.

lengths and 0.5 $\mu$m wavelength for different light intensities, the $I$–$V$ characteristic for different wavelengths and light intensities which is shown in Fig. 5

The response spectra of this structure for different biased voltages are shown in Fig. 6. With the increase of biased voltage, peak current intensity tends to saturate. With SiC/ $SiC_{0.8}Ge_{0.2}$ hetero-structure, when based voltage is 2 V, the device can obtain the peak current intensity around the visible light regions of 0.49–0.52 $\mu$m, and has a peak of 330 mA/W for the wavelength of 0.5 $\mu$m and even reach the 76.2 mA/W near infrared regions of 0.7 $\mu$m.

## 4. Conclusion

The optically controlled SiC lateral power transistor based on SiC/ $SiC_{0.8}Ge_{0.2}$ superjunction structure have a good spectra response to the visible lights, especially in the range of 0.49–0.52 $\mu$m, and breakdown voltage has a linear relationship with drift region length. For 2 V based voltage, the responsivity of the device at 0.5 $\mu$m and 0.7 $\mu$m are 330 mA/W and 76.2 mA/W respectively.

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