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Si/SiGe Heterojunction Phototransistors: Physics and Modeling

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INTRODUCTION

The heterojunction phototransistor (HPT) can be used in the front end of the optical receiver for the optoelectronic integrated circuits (OEICs). In order to overcome the drawback of weak photo-absorption process in Si material and the problems in system integration of III-V based photodetectors [1], the Si/SiGe HPT with 850nm absorption is demonstrated. In this work, we report the results of Si/SiGe HPT at 850nm wavelength operation. A compact model for the HPT is also proposed.

Si/SiGe MQW HPT

The $Si_{0.5}Ge_{0.5}$/Si multiple quantum wells (MQW) are placed between the base and collector of Si/SiGe heterojunction bipolar transistors as light absorbing layers. The phototransistor with high responsivity and bandwidth at 850nm is demonstrated (Fig. 1) [2]. Efficient near infrared (1310nm) photoresponse also achieved in this device. The results indicate the Si/SiGe phototransistor is suitable for front-end photoreceivers in the high-speed optical communication applications.

SPEED ENHANCEMENT

The speed performance of Si/SiGe HPT at the wavelength of 850nm can be enhanced by the use of the substrate terminal of Si/SiGe HPT, with the slight expense of optical gain reduction as compared to the same HPT using traditional dc base bias technique. Under proper optical power excitation and substrate terminal biasing, 1.5GHz electrical bandwidth with reasonable responsivity can be achieved simultaneously.

Moreover, the speed and avalanche responsivity of the Si/SiGe HPT can be further enhanced by proper design of the non-ideal (nkT) base recombination current, with a reasonable normal responsivity. Four sets of HPTs are designed (Fig. 2). With extra nkT base current, device D shows a weak tail in the impulse response, which yields a larger bandwidth than that of device C (3 GHz vs. 1.5 GHz). This improvement is due to the extra nkT recombination current at E-B depletion region (nkT current) of device D which removes the excessive photo-generated holes in the base. This extra nkT base current also gives a wide bias range for avalanche gain operation. With proper nkT base current and a BV_{CE} (light) much lower than BV_{CEO} (dark), a high avalanche gain (~ 2,000) with responsivity larger than 100 A/W at 1 μW light exposure can be achieved.

MODELING OF THE HPT

On the other hand, the integration of the photodetector is also essential for optical communication chips. The HPT is integrable with SiGe HBT process and can be modeled by a modified MEXTRAM model for the circuit simulation (Fig. 3) [3]. The impact ionization to obtain an extra gain for the optoelectronic conversion and the "Early voltage reduction" under constant illumination are well-modeled in a modified model. The nkT recombination current and the substrate contact to enhance the HPT speed are incorporated in ac model. It shows a good agreement between measurement and simulation.

SUMMARY

We have demonstrated a novel Si/SiGe heterojunction phototransistor with high responsivity and bandwidth at 850nm wavelength. It can achieve better speed improvement with much less photocurrent reduction utilizing substrate termination technique. The properly designed nkT base current can also increase the speed of HPT, and have an avalanche region with extremely high gain. A modified MEXTRAM model is used to model the HPT. Good agreement between measurement and simulation is demonstrated.

REFERENCES

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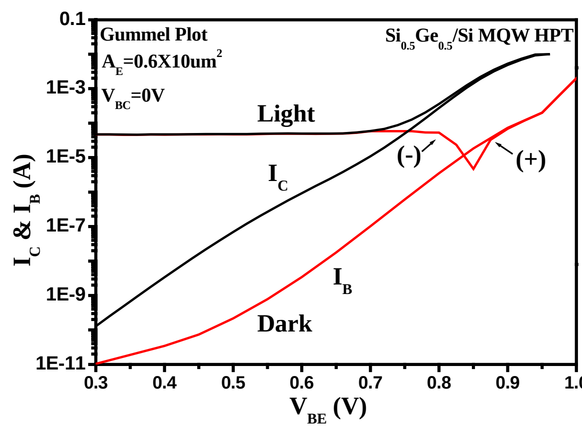

Fig.1 Gummel plots of a SiGe phototransistor with and without 850nm light.

	A	B	C	D
SiGe MQW	Yes	Yes	No	No
Current Gain	~ 3,000	~200	~ 100	~ 100
Extra nkT I_B	No	Yes	No	Yes
Responsivity	17.5	1.2	0.36	0.43
FWHM	270ps	140ps	~90ps 1.5GHz	~90ps 3GHz

Fig. 2 The major design differences of SiGe HPTs. The SiGe/Si MQWs are placed in between the base and collector when indication is "Yes".

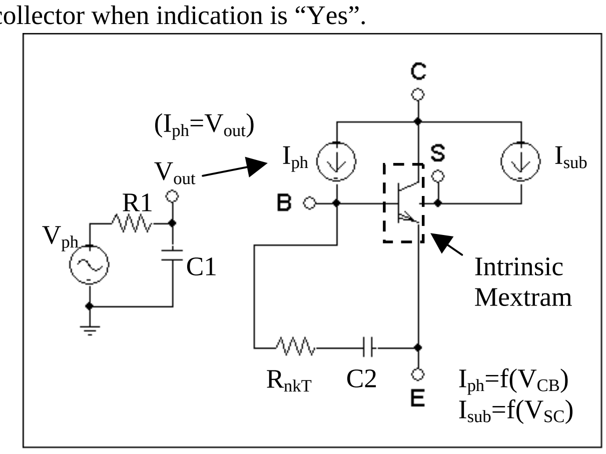

Fig. 3 The equivalent circuit of the HPT used in SPICE. The photocurrent is modeled as the two current sources at the collector-base and the collector-substrate junction. They are function of V_{CB} and V_{SC}, respectively.