Si/SiGe Heterojunction Phototransistor

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Abstract:

We review our recent progress in the development of high-speed SiGe based heterojunction phototransistor (HPT). High responsivity and high electrical bandwidth at the 850nm wavelength have been achieved. The good performances of HPTs imply their applications in short-reach optical fiber communication.

Summary:

High-speed Si-based photodetectors (PDs), which are operated at 850nm wavelength for the applications of short-reach data communication, merit a lot of attentions [1] due to their low cost and good ability to integrate with the matured Si-based electronic industry. In order to overcome the intrinsic material drawbacks of Si, several approaches have been reported, such as, deep trench structure [2], silicon on insulator (SOI) substrate [1], and wafer-bonding mirrors [3]. These techniques will increase the cost and difficulty in system integration. In this paper, we review our recent progress on the development of integrable SiGe based heterojunction bipolar phototransistors (HPTs) which can achieve high bandwidth and responsivity performances by an additional terminal and multiple-quantum wells (MQWs) at base-collector (B-C) junction. Two types of HPT were fabricated by a baseline process of SiGe/Si based heterojunction bipolar transistors (HBTs). One HPT has the typical epi-layer structure of standard HBT. The other one has similar structure with previous HPT, except that an additional Si0.5Ge0.5/Si MQWs are incorporated in the
B-C junction as shown in Figure 1 [4]. In spite of the additional MQW photo-absorption layer, this structure still remains good $f_t$ (28GHz) performance.

![Cross-sectional view of HPT with SiGe/Si MQWs at B-C junction](image)

**Fig. 1** Cross-sectional view of HPT with SiGe/Si MQWs at B-C junction

Figure 2 shows the measured photocurrent of the HPTs under C-E (phototransistor) and B-C (p-i-n) operation modes [4].

![Photocurrent vs. $V_{CE}$ or $V_{BC}$ voltages for (a) HPT without MQWs and (b) HPT with MQWs under C-E and B-C operation modes](image)

**Fig 2.** Photocurrent vs. $V_{CE}$ or $V_{BC}$ voltages for (a) HPT without MQWs and (b) HPT with MQWs under C-E and B-C operation modes.

The responsivity of the HPT with MQWs is enhanced greatly as compared with the HPT without MQWs due to larger photo-absorption constant of SiGe MQWs than bulk Si materials [4]. Higher responsivity than the reported values can be expected by use of anti-reflection coating on the HPTs and fiber lens for focusing the input optical beam. In order to improve the speed performance of HPTs, dc bias voltage or current across base-emitter (B-E) junction is necessary [5]. However, this approach will result in huge dark current, large power consumption, and reduction in operation gain [5]. In
our demonstrated SiGe HPTs, by connecting the p-type substrate terminal with emitter, the speed performance can be improved significantly without sacrificing operation gain and increasing dark current seriously. Figure 3 shows the improvement in pulse-width of the measured HPT with MQWs by utilizing substrate and base terminals.

The transient impulse responses of HPTs were explored by a sampling oscilloscope, which was driven by the 830nm Q-switch laser with 50ps optical pulse-width. It is concluded that the speed performances using the substrate terminal technique can be improved more significantly with much less responsivity (photocurrent) reduction as compared to the base termination technique. In order to further obtain the highest speed performances of these HPTs, the input optical power was reduced to the level that the shape of measured impulse response was independent of input optical power. Figure 4 shows the measured impulse responses and their corresponding frequency responses are also shown in the insets.
The HPTs with an ordinary SiGe HBT structure exhibit much higher speed performance (1.5GHz) than the HPTs with MQWs (0.55GHz). The deconvolved impulse response of Figure 4(a) shows a pulsewidth about 74ps and its corresponding electrical bandwidth is about 3GHz. The reasonable responsivity (over 0.4A/W) [1] and high electrical bandwidth performances (~3GHz) of standard HPT structure ensure its application of short-reach data communication. With respect to the HPT with MQWs layer, its high responsivity (over 17A/W) and fT (28GHz) performances can find applications in low-cost clock recovery circuits or optoelectronic mixer [6]. The newest measurement results will be presented in the conference.

Reference