Multi-Finger Power SiGe HBT with Non-Uniform Finger Spacing*

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Abstract: A multi-finger power SiGe heterojunction bipolar transistor (HBT) with non-uniform finger spacing was fabricated to improve thermal stability. Experimental results show that the peak temperature is reduced by 22K compared with that of an HBT with uniform finger spacing in the same operating conditions. The temperature profile across the device can be improved at different biases for the same HBT with non-uniform finger spacing. Because of the decrease in peak temperature and the improvement of temperature profile, the power SiGe HBT with non-uniform spacing can operate at higher bias and hence has higher power handling capability.

Key words: SiGe; HBT; power
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1 Introduction

Because of the high current handling capability, high cutoff frequency, and high maximum oscillation frequency, the heterojunction bipolar transistor (HBT) has become an increasingly important semiconductor device in power amplifiers for RF and microwave applications[1,2]. Power HBTs usually employ a multi-finger structure to improve their current handling capability and thermal dissipation capability. However, self-heating effects on each emitter finger and thermal coupling effects among emitter fingers result in the thermal instability of power HBTs, which limits their power handling capability.

In order to alleviate the thermal effects in multi-finger HBTs, several techniques can be used, including the use of an emitter ballasting resistor[3], a base ballasting resistor[4], and variable emitter finger widths[5,6]. The value of the ballasting resistor should be carefully designed to minimize the expense of device speed, while the optimization of variable finger widths is complicated and strongly depends on biasing conditions. In this work, a power SiGe HBT with non-uniform finger spacing was fabricated. It is found that the thermal stability of the power HBT can be improved substantially by adjusting the spacing of the fingers. For the non-uniformly spaced device, the peak temperature is decreased by increasing the spacing between fingers in the center region. The experimental results show that the power HBT with non-uniform finger spacing provides a better temperature profile with no apparent adverse effects on the device's electrical characteristics compared to the traditional uniform spacing design.

2 Device structure and fabrication

Figure 1 is a schematic cross-sectional view of a SiGe HBT with multiple emitter fingers, in which the insert gives the specifications of all the layers. The Ge content in the uniform SiGe base layer is 16%, and the SiGe HBT is interdigitated and composed of 20 emitter stripes with an area of 3μm × 60μm for each stripe. After the growth of the collector/base/emitter layers by ultrahigh vacuum chemical vapor deposition (UHVCVD),

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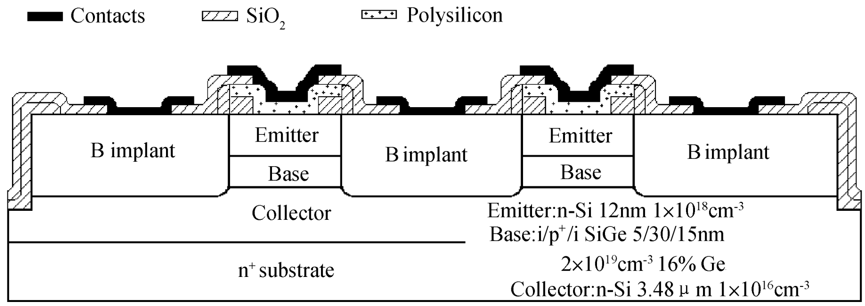

Fig.1 Cross section of a SiGe HBT with multiple emitter fingers

the SiGe HBT was fabricated in the following steps:

(1) Low temperature growth of SiO_2;

(2) Etching of emitter area;

(3) Depositing polysilicon of 200nm by low pressure chemical vapor deposition (LPCVD) and implantation of P (energy of 70keV and dose of $1\times10^{16}cm^{-2}$) for the emitter contact;

(4) Dry etching of emitter mesa;

(5) Implantation of BF_2 (energy of 25keV, dose of $1\times10^{15}cm^{-2}$) and B (energy of 30keV, dose of $1\times10^{15}cm^{-2}$) for the base contact;

(6) Dry and wet etching of collector mesa;

(7) Lower temperature growth of SiO_2; etching the SiO_2 inside the mesa with other area masked by photo resist;

(8) Sputtering Ti; forming TiSi alloy in the contacting area by rapid thermal annealing (15s at 850℃);

(9) Depositing SiO_2 of 200nm by LPCVD and Si_3N_4 of 200nm by plasma-enhanced chemical vapor deposition (PECVD);

(10) Opening the contact holes of emitter and base;

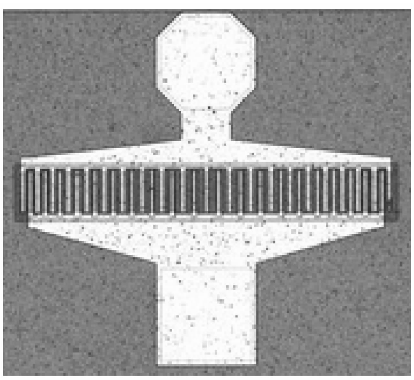

Fig.2 SEM photo of the surface of the fabricated 20-finger power SiGe HBT with non-uniform finger spacing Both the emitter and base metal stripe widths are 5μm.

(11) Sputtering Al, forming AlSi of 1μm;

(12) Depositing SiO_2 of 300nm and Si_3N_4 of 750nm by PECVD after the photolithography of EB metal strips, then passivating the surface by polyimide;

(13) After thinning the substrate to 150μm, evaporating Au on the back side and scribing die, the dies were packed in metal package to finish the fabrication of the power SiGe HBT.

3 Experimental results and discussions

Figure 2 is an SEM photo of the surface of the fabricated 20-finger power SiGe HBT with non-uniform finger spacing, where both the emitter and base metal stripe widths are 5μm. For a 20-finger HBT, there are 19 spacing values, which are measured from the center of each emitter finger. Because of the symmetry, there are only 10 different spacing values to be designed. We label the values $X_1, X_2, \cdots$, and X_{10}, where X_{10} denotes the center spacing. The finger spacing values of both non-uniformly spaced and uniformly spaced structures are shown in Table 1. Both non-uniform and uniform HBTs have the same structure in each finger and the same total spacing.

Infrared micro photos of 20-finger SiGe HBTs with uniform and non-uniform finger spacing are shown in Figs.3(a), (b), and (c), respec-

Table 1 Finger spacing values of 20-finger SiGe HBTs

Device	Finger spacing values									
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
Uniform spacing/μm	15	15	15	15	15	15	15	15	15	15
Non-uniform spacing 1 /μm	11	11	13	13	15	15	17	17	19	23
Non-uniform spacing 2 /μm	10	11	12	13	14	15	16	17	17	17.5

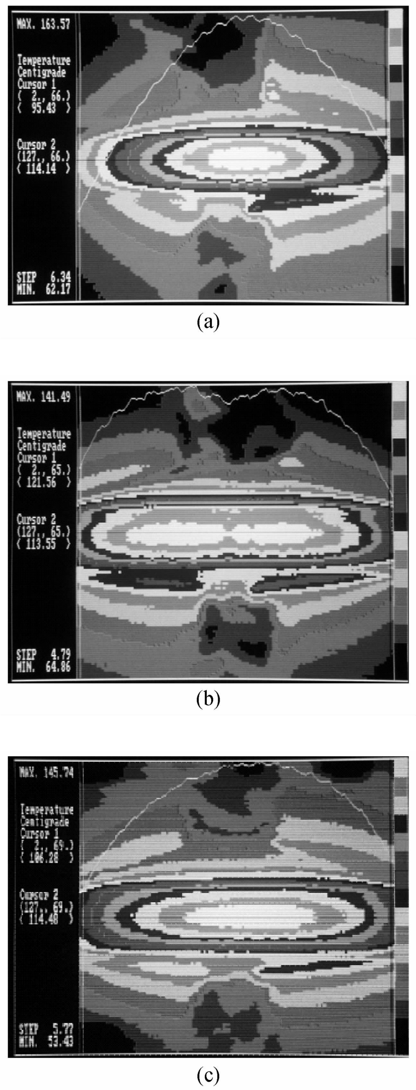

Fig. 3　Infrared micro photos of 20-finger SiGe HBTs with uniform finger spacing (a), non-uniform finger spacing 1 (b), and non-uniform finger spacing 2 (c)

tively. All of them operate in the same conditions, with I_C = 800mA and collector-emitter voltage V_{CE} = 5V. We can see that the peak temperature of the uniformly spaced HBT is 436.57K (163.57℃), while that of the HBT with non-uniform spacing in Fig. 3 (b) is only 414.49K (141.49℃) which is less by 22K. It is clear that the decrease in peak temperature avoids the problem of local hot spots. The uniformity of temperature profile is improved significantly for the HBT with non-uniform finger spacing. At the same time, the electrical characteristics of the HBTs with uniform and non-uniform spacing are nearly the same, as shown in Fig. 4. Therefore, the HBT with non-uniform finger spacing provides a better

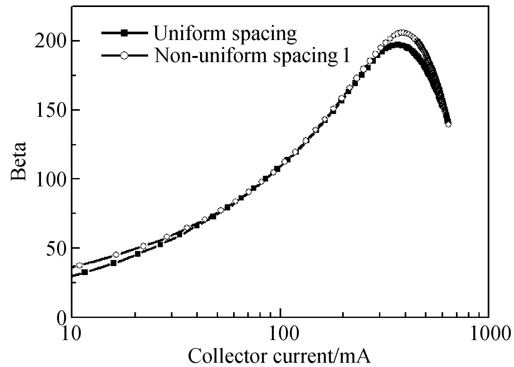

Fig. 4　DC current gain versus collector current for HBTs with uniform and non-uniform finger spacing

temperature profile with no apparent adverse effect on the device's electrical characteristic compared to the traditional uniform finger spacing design.

In order to optimize the non-uniform finger spacing values, we present two kinds of non-uniform finger spacing designs. Infrared micro photos of them are shown in Figs. 3 (b) and (c). Compared with non-uniform spacing design 1, the peak temperature of non-uniform spacing design 2 is higher [418.74K (145.74℃)] in the same operating conditions of I_C = 800mA and V_{CE} = 5V. Therefore, the temperature improvement of non-uniform spacing design 1 is better than that of non-uniform spacing design 2 for our devices. The optimization of non-uniform finger spacing values in power HBTs is investigated in our previous paper[7]. In the following, we will take non-uniform spacing design 1 for example to discuss the temperature profile of power HBTs with non-uniform and uniform finger spacing.

The temperatures profile of 20-finger SiGe HBTs with non-uniform and uniform finger spacing at different biases are shown in Fig. 5. For the same non-uniformly spaced HBT, the peak temperature is reduced significantly at different biases. The higher the bias is, the better the improvement of peak temperature is. It is shown in Fig. 5 that the non-uniform design only reduces device peak temperature by 6.3K when I_C = 200mA, but by 22K when I_C = 800mA. Since the heat caused by power dissipation is little at low current (I_C = 200mA), the temperature difference in emitter fingers is not significant for the uniformly spaced HBT. But, when the HBT operates at a high current (I_C = 800mA), the peak temperature will in-

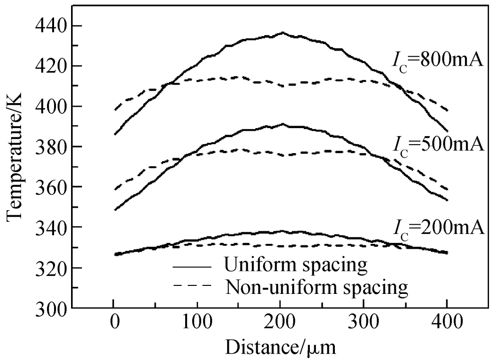

Fig. 5 Temperature profile of 20-finger SiGe HBTs with non-uniform and uniform finger spacing

crease significantly. Therefore, the improvement of peak temperature is obvious for the power HBT with non-uniform spacing.

Figure 6 shows the peak temperature versus power P for SiGe HBTs with uniform and non-uniform finger spacing. We can see that the peak temperature improvement of the HBT with non-uniform spacing is more significant when the device operates at higher power P. Furthermore, the HBT with non-uniform spacing could provide more power P when uniform and non-uniform devices operate at the same peak temperature.

4 Conclusions

A power SiGe HBT with non-uniform finger spacing was fabricated to improve thermal stability. Experimental results show that the uniform spacing design results in a higher temperature at the center fingers. For the SiGe HBT with non-uniform finger spacing, the peak temperature was 22K lower than that of the HBT with uniform spacing. For the same non-uniformly spaced HBT, non-uniformity of temperature among the fingers was improved noticeably at different biases. The improvement of peak temperature in the non-uniformly spaced HBT was more significant when the device operated at higher power P. Because of the decrease in peak temperature and the improvement of temperature profile, the power SiGe HBT with non-uniform spacing can operate at higher current (I_C) and hence has higher power handling capability.

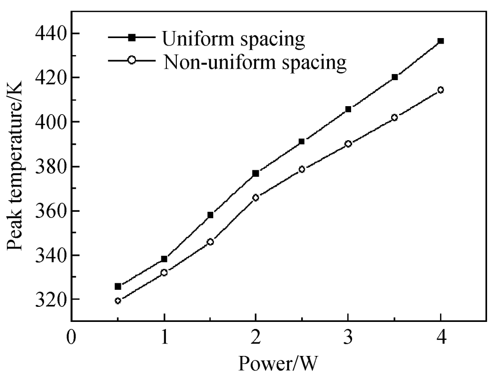

Fig. 6 Peak temperature versus power for SiGe HBTs with uniform and non-uniform finger spacing at V_{CE} = 5V

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非均匀条间距结构功率 SiGe HBT*

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摘要： 成功研制出非均匀发射极条间距功率 SiGe 异质结双极晶体管（HBT）用以改善功率器件热稳定性.实验结果表明，在相同的工作条件下，与传统的均匀发射极条间距 HBT 相比，非均匀结构 HBT 的峰值结温降低了 22K.在不同偏置条件下，非均匀结构 SiGe HBT 均能显著改善芯片表面温度分布的非均匀性.由于峰值结温的降低以及芯片表面温度分布非均匀性的改善，采用非均匀发射极条间距结构的功率 SiGe HBT 可以工作在更高的偏置条件下，具有更高的功率处理能力.

关键词： SiGe；异质结双极晶体管；功率

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