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1570V, 14A 4H-SiC Bipolar Darlington with a High Current Gain of β>462

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This paper reports the design, fabrication and characterization of a 4H-SiC bipolar Darlington with both high DC commom emitter current gain and high voltage. The driving and output transistors are designed and fabricated on the same chip with a 12um, $8.5\times10^{15}cm^{-3}$ doped drift layer and a 1um $4.1\times10^{17}cm^{-3}$ doped p base. The Darlington's drive transistor is capable of 1,600V and 5A with a maximum current gain β_1 over 25 at a collector current density J_{C1}=250A/cm^2 with a specific on-resistance (R_{SP_ON}) of 12.2mΩcm^2. The output transistor can handle over 23A and a blocking voltage higher than 1600V with a peak current gain $\beta_2 > 22$ at J_{C2}=261A/cm^2 and an R_{SP_ON} of 13.4mΩcm^2. The Darlinton's DC current gain at room temperature is found to increase with the collector current, up to 462 at I_{C2}=13.9A (232A/cm^2), limited by the measurement instrument. The Darlington can block voltages up to 1571V, conduct an I_C=14A at V_F= 7.5V and provide a differential R_{SP_ON} of 16.7mΩcm^2 at J_{C2} up to over 240A/cm^2. Temperature-dependent I-V characteristics will be presented for the driving and output transistors. DC commom emitter current gains will also be reported for the driving and output transistors as well as the Darlington.

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Introduction

4H-SiC is the most promising update material to Si in the high power, high temperature field. Because of the reliability problem related to the gate oxide, as well as the low channel mobility in SiC MOSFET research, SiC BJTs have recently gained increased attention because it is free of the gate oxide related problems[1,2,3]. Besides, being a bipolar device, SiC BJT has the advantages of capable providing higher current with lower on-state resistance. In addition, BJT is a quite fundamental semiconductor device. The center disadvantage of SiC BJTs, however, is the low current gain or the high base driving current requirement. Darlington transistor can drastically reduced the base current requirement but at the expense of increased forward voltage drop (V_F), making Darlington attractive only at relatively high voltage region. Earlier efforts include a monolithic 4H-SiC Darlington of ~500V, 50A/cm^2 (0.3A) at V_{CE}=7.5V with a gain of 450 at J_C~8A/cm^2, decreasing to ~50 as J_C increasing to ~50A/cm^2 [4] and a hybrid Darlington of 500V, >200A/cm^2 (>23A) at V_{CE}=6.4V with a gain of 430 at J_C~200A/cm^2 [5]. This paper reports a substantially higher voltage (1,570V) Darlington with I_C=14A (233A/cm2) at V_F= 7.5V and a gain >462.

Fabrication and Characterization

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The 4H-SiC Darlington drive (active area=1.2mm^2) and output transistors (active area=6mm^2) are fabricated on the same chip designed with a drift layer 12um doped to ~8x10^{15}cmand a 1um p base doped to ~4x10^{17}cm^{-3}, by the following steps : (1)Emitter finger mesa formation by ICP etching ; (2) C plus Al co-implantation in the base contact region ; (3)Junction termination plus a shallow device isolation ICP etching ; (4)Surface passivation by wet oxidation at 1100°C with Ar annealing and low temperature wet oxygen re-oxidation; (5)Ohmic contact formation using Al-free, sputtered Ti covered by TiN for the p+ base and n+ emitter and Al covered by Ni for the substrate n+ collector ; (6) Au overlay metal and bonding pad formation; (7) Die mounting and ribbon bonding to package the Darlington. The Darlington package containing a monolithic multi-cell chip is completed by connecting the emitter pin of the drive transistor to the base pin of the output transistor. Fig.1 shows the formation of the Darlington transistor. The fabricated 4H-SiC bipolar Darlington transistor is characterized both at the room temperature and at 150°C. Fig.2 shows the I-V characteristics of the driver. The peak current gain is >25 at I_{C1}=3A (250A/cm^2) and V_{CE1}=5V at room temperature with a specific on-resistance (R_{SP_ON}) of 12.2mΩcm^2. Fig.3 shows the I-V characteristics of the output transistor with a peak current gain of 22.3 at I_{C2}=15.6A (260A/cm^2) and V_{CE2}=4.6V with an R_{SP_ON} of 13.4mΩcm^2. The Darlington I-V characteristics at RT are shown in Fig.4. A very high DC current gain 462, limited by measurement set up, is obtained at 13.9A (~231A/cm^2) at room temperature. The Darlington I-V characteristics at 150C are shown in Fig.5. The Darlington current has been measured to ~5A at 150C, limited again by measurement set-up. The Darlington maintains a high gain of 150 at 150C ambient temperature. The detailed design and fabrication will be reported along with other measurement results, including the gains of the transistors as a function of current and temperature and the specific on-resistance also as a function of temperature.

References

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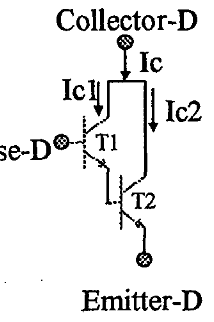
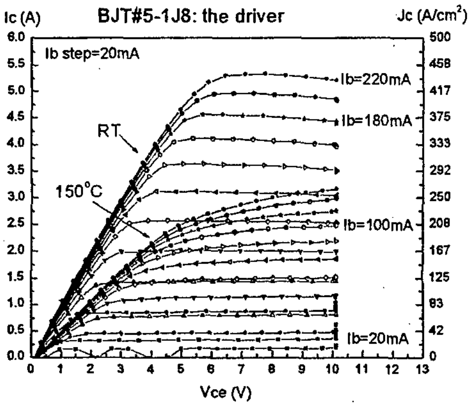
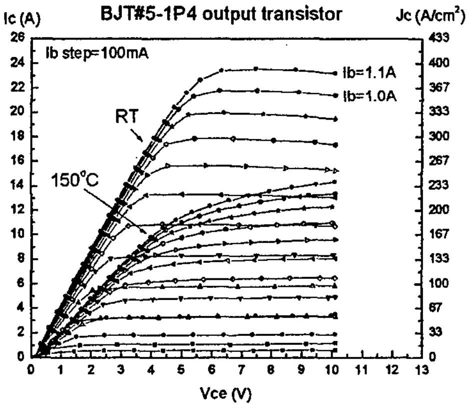
[4] Y. Tang and T.P. Chow, ISPSD-2003, p. 383, Cambridge, UK, April 14-17, 2003.

(a)




BJT#5-1J8: the driver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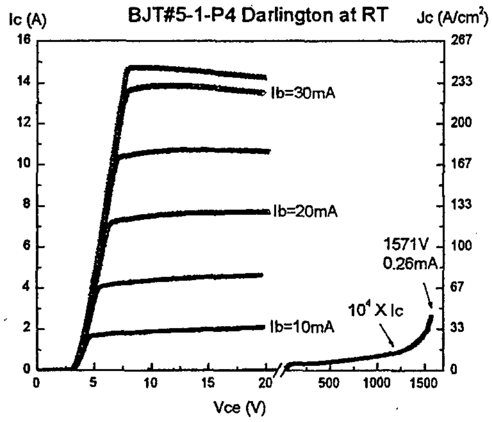
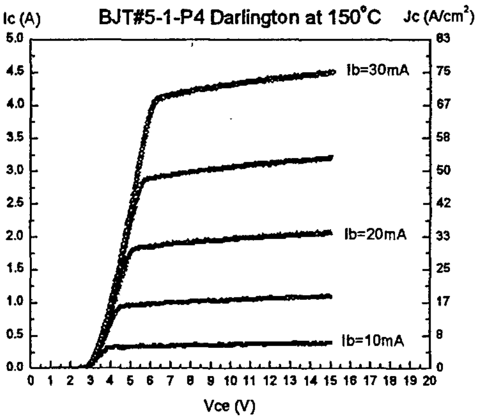

BJT#5-1-P4 Darlington at RT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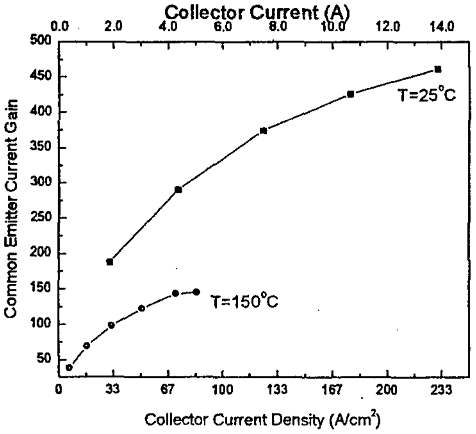

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