Bipolar Reliability Optimization through Surface Compensation of the Base Profile

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Abstract

Increased reliability of advanced bipolar devices is achieved by compensating the surface of the base doping profile with a shallow, low-dose arsenic implant. An order of magnitude increase in lifetime is obtained without a degradation in ECL gate delay or f_T, while a 100X improvement in lifetime is exhibited with approximately a 20% degradation in gate delay and f_T. This technique is applicable to non-self-aligned as well as self-aligned bipolar devices.

Introduction

One of the major reliability concerns for bipolar transistors is the degradation of current gain due to the application of a reverse bias to the emitter-base junction [1-7]. As devices continue to scale down, the base doping increases, resulting in larger electric fields and further aggravating this bipolar reliability problem. This paper presents a technique for increasing the reliability of advanced bipolar devices by compensating the surface of the base doping profile with a shallow, low-dose arsenic implant.

Honda et al. [8] proposed using a phosphorous implant to form an n- region adjacent along the edge of the n+ emitter, which was also formed by ion implantation. For polysilicon-emitter structures, the emitter is very shallow and thus it is difficult to form a phosphorous region that is shallower than the emitter. Although the results of Honda et al. showed much improvement in bipolar reliability, no results were presented regarding ac performance.

Process

The bipolar structures used in this work were made in a 0.5μm BiCMOS technology [9]. This process employs self-aligned complementary buried layers and twin wells, FMPBL isolation, a 150Å gate oxide, surface channel NMOS and buried channel PMOS transistors with effective channel lengths down to 0.35 and 0.50 μm respectively, n-/p- LDDs formed with a disposable polysilicon spacer process, and two levels of metallization. Three levels of polysilicon are included: the first forms the MOSFET gates, the second the bipolar emitter and self-aligned contact landing pad; and the third a teraohm load resistor in the bit cell.

Figure 1 shows a cross-section of a bipolar transistor with the surface concentration of the base region formed by a 4E13 cm^{-2} base implant and then compensated by an arsenic implantation. The energy of the As implant was chosen to place the As peak just beneath the surface, with doses ranging from 5E12 to 5E13 cm^{-2}. Simulations shown in Figure 2 indicate that the base surface concentration of 5E18 cm^{-3} is reduced to about 2E18 cm^{-3} with a 1E13 cm^{-2} arsenic dose and that the surface becomes inverted with an As dose of 5E13 cm^{-2}.

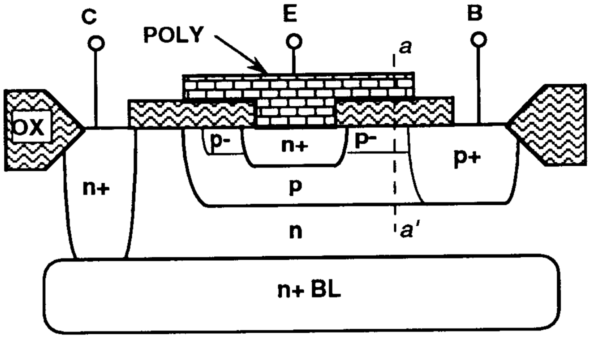

Fig 1: Cross-section of a bipolar transistor with an arsenic implant to compensate the surface of the base profile. The compensation implant is done at the same time as the base implant, thus requiring no additional masks.

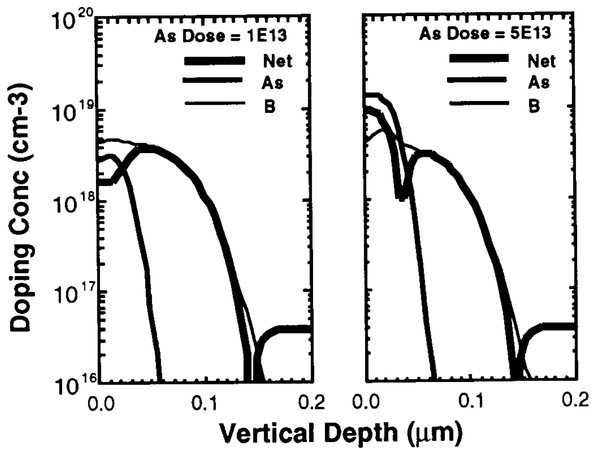

Fig 2: Simulated doping profiles for the base region along the a-a' line in Fig. 1. The base surface concentration of 5E18 cm^{-3} is decreased to less than 2E18 cm^{-3} with a 1E13 cm^{-2} arsenic dose and becomes inverted for a dose of 5E13 cm^{-2} .

DC Characteristics

Figure 3 shows the dependence of the current gain on the arsenic dose. The reduction in current gain with increasing dose is caused by an increase in base current, Ib, as shown in Figure 4. One reason for the increase in Ib is the higher current along the emitter periphery due to the lower surface base doping. Because the n+ emitter diffused from the polysilicon is shallow, the As implant increases the pinch base resistance, see Figure 5, and increases the collector current. For the 5E13 cm^{-2} As dose, the dc characteristics are considerably different from the control as observed in Figure 6. The non-ideality of the base current and the large collector current are due to the extension of the emitter with a shallow n-region, creating a parasitic npn bipolar in parallel with the normal device. For devices without the arsenic compensation implant, a larger low-level non-ideal base current was observed, as seen in Figures 3 and 6, perhaps due to tunneling from the large electric field at the emitter-base junction.

AC Performance

One advantage of the base compensation along the emitter periphery is the reduction in emitter-base capacitance, Cbe, seen in Figure 7. The sharp increase for the largest dose results from the n- extension of the emitter which increases the emitter area. Figures 8 and 9 show that the peak f_T and ring oscillator delay remain the same up to the 1E13 cm^{-2} dose and degrade with larger doses. The decrease in Cbe with increasing dose improves both f_T and ring oscillator delay [10,11]. But, the increased two-dimensional effects with reduced surface doping (and the increased base resistance for ECL delay) cancel the Cbe improvement for the lowest arsenic doses and become dominant for larger arsenic doses.

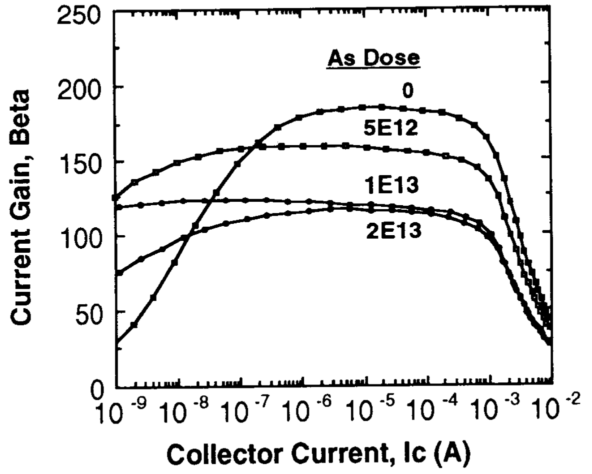

Fig 3: Measured current gain for different doses of the base compensation implant. The current gain decreases with increasing dose.

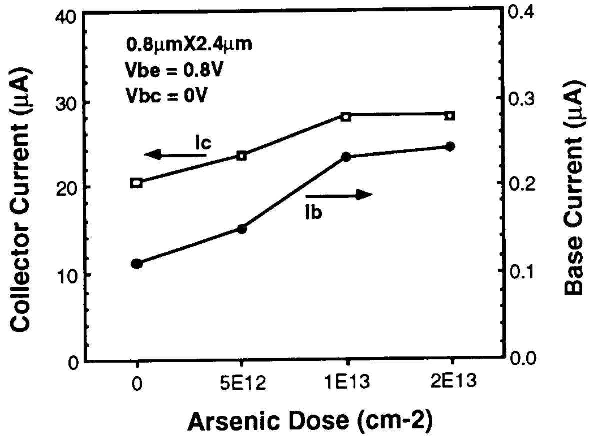

Fig 4: Collector and base current dependence upon arsenic dose for the base compensation implant. Both currents increase with increasing dose, with the base current increasing faster.

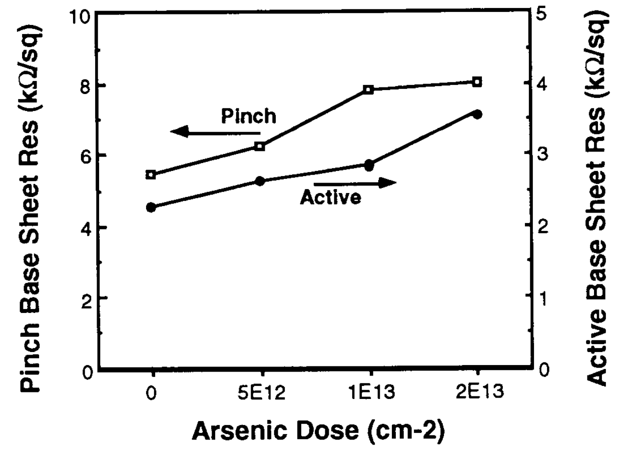

Fig 5: Pinch base and active base (not under the emitter) sheet resistance as a function of arsenic dose. The base compensation implant increases both the pinch and active base sheet resistance.

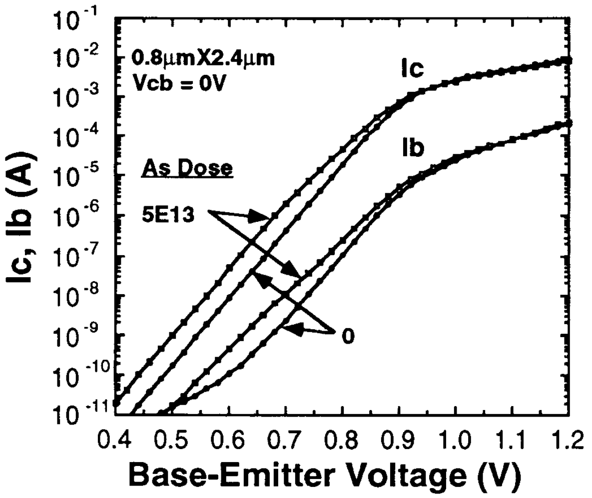

Fig 6: Measured Gummel plots for devices without a base compensation implant and with an implant dose of 5E13 cm^{-2}. The large currents and non-ideality of the base current for the 5E13 As dose device result from the extension of a shallow emitter into the base area.

Reliability Improvement

The base compensation significantly reduces the peripheral electric field and thus reduces the reverse current of the emitter-base junction, as seen in Figure 10. The impact upon bipolar reliability was determined by measuring the increase in base current, ΔIb, due to a reverse emitter-base bias of 4V. Figure 11 shows the decrease in ΔIb with increasing As dose, while Figure 12 shows a plot of the device lifetime with lifetime defined as a ΔIb of 0.5μA (ß=50 at Vbe=0.8V for the control). With the As compensation implant, the lifetime is improved by 10X and 100X with the 1E13 cm^{-2} dose and 2E13 cm^{-2} dose, respectively.

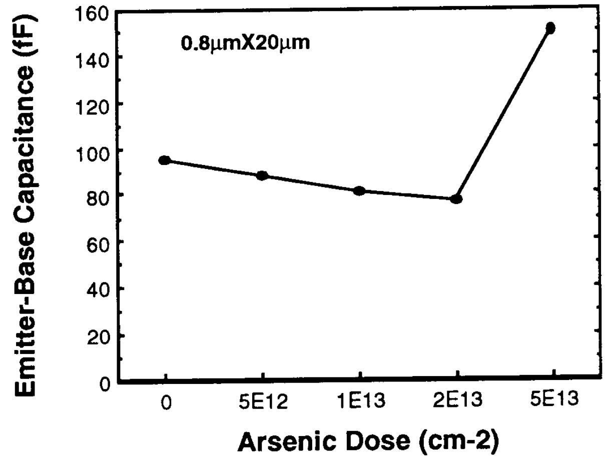

Fig 7: Emitter-base capacitance variation with arsenic implant compensation dose. The capacitance decreases with increasing compensation until the base surface becomes inverted to n-type with the 5E13 dose, creating a much larger emitter area.

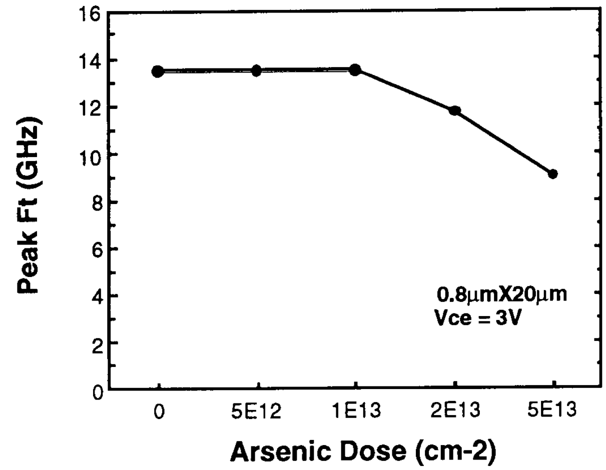

Fig 8: Dependence of peak f$_T$ upon the dose of the compensation implant. The peak f$_T$ remains the same for the two lowest arsenic doses, but decreases with larger doses.

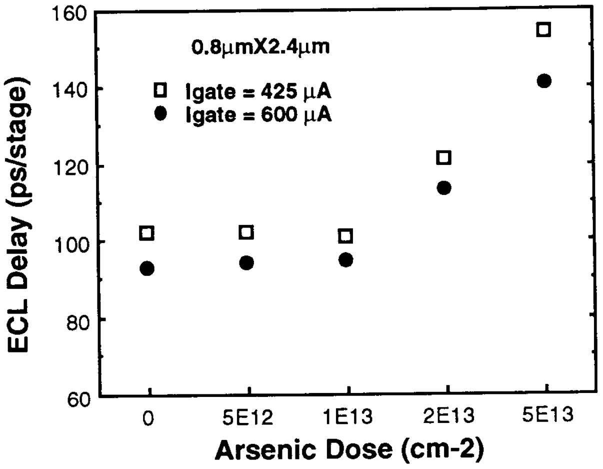

Fig 9: ECL ring oscillator delay as a function of arsenic dose. The 15-stage ring oscillators had a voltage swing of 500 mV. The delay does not degrade for the two lowest arsenic dose, but degrades by 20% for the 2E13 dose.

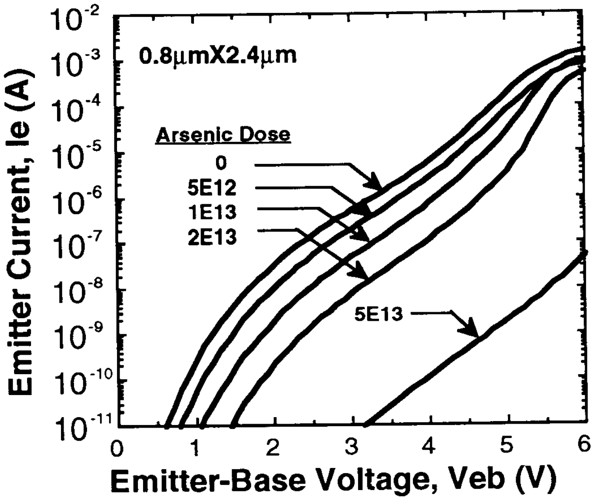

Fig 10: Reverse I-V characteristics of the emitter-base junction for different arsenic compensation implants. The reverse current decreases with increasing dose, with a reduction in current (for < 5V) of about 10X for a 1E13 dose and 100X for a 2E13 dose. The 5E13 characteristic breaks down sharply at 6.5 V.

Conclusions

A shallow, low-dose arsenic implant has been used successfully to increase the reliability of bipolar devices while maintaining good bipolar performance. These results indicate that compensating the base profile is an effective technique in extending the reliability of bipolar transistors.

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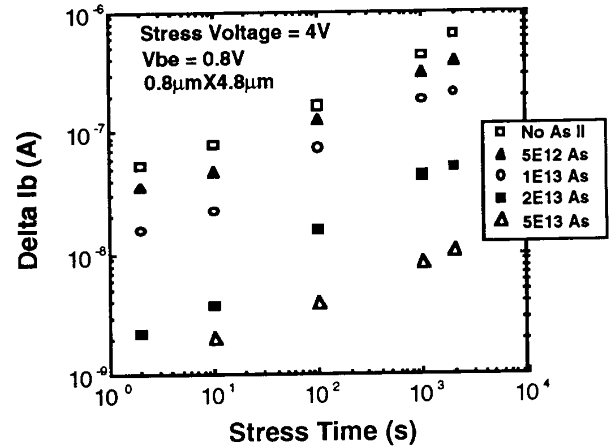

Fig 11: Increase in base current, ΔIb, as a function of accumulated stress time for a constant reverse stress voltage of 4V. The degradation decreases with increasing dose.

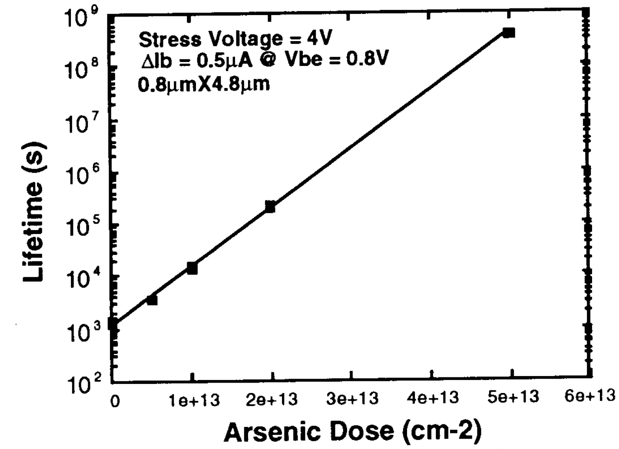

Fig 12: Dependence of device lifetime upon the dose of the compensation implant. The lifetime is defined as ΔIb = 0.5 μA at Vbe = 0.8 V (which gives β=50 for the conventional device) at a constant reverse stress of 4V. The lifetime is improved by 10X for the 1E13 dose and 100X for the 2E13 dose.

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