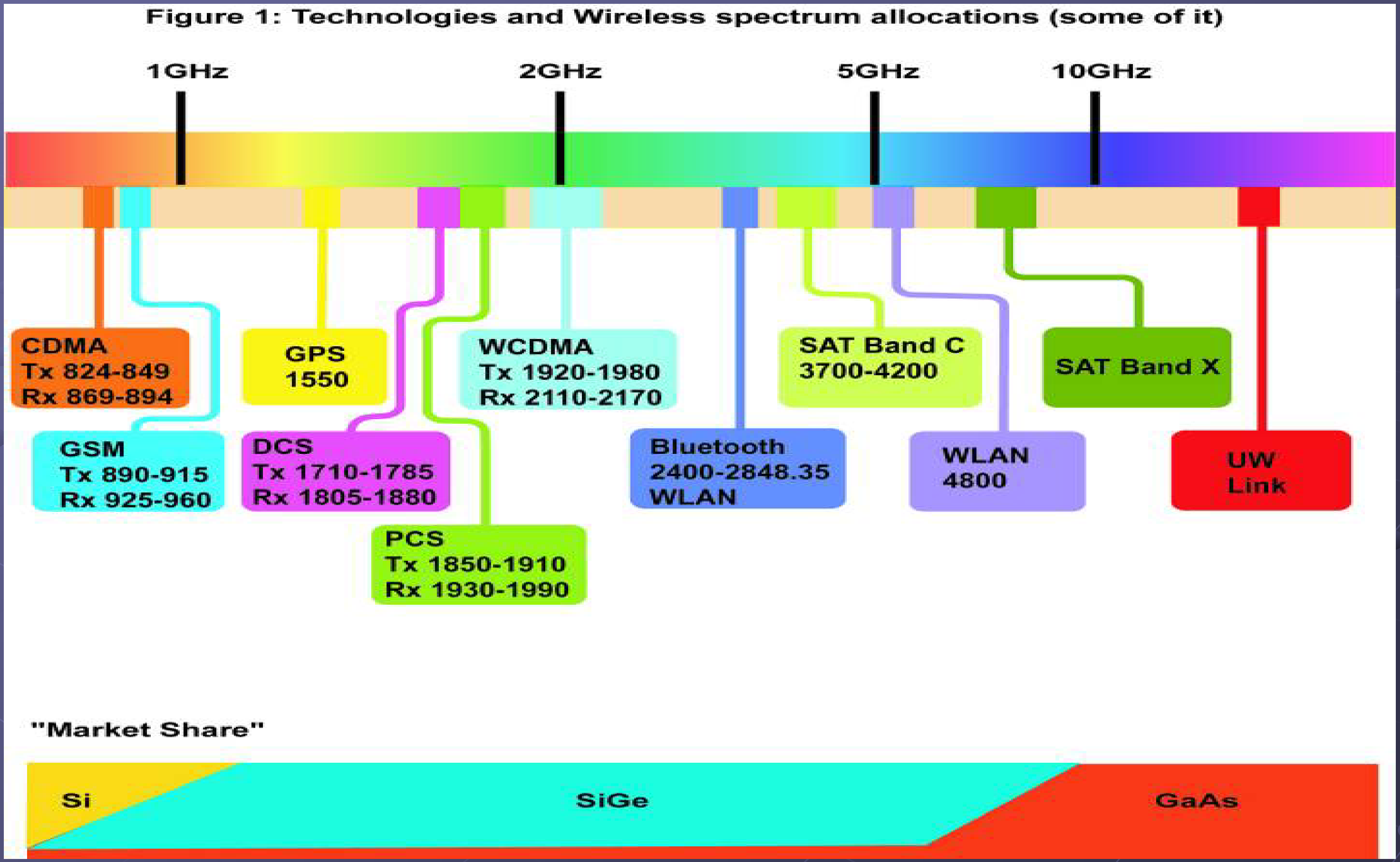
How Germanium Doping Improves BJT Performance in Wireless Communications

Background: SiGe's role in wireless



Background: SiGe's role in wireless

Parameter	Si BJT	SiGe HBT	III-V
F_T (GHz)	25-30	40-70[1]	250
F_{MAX} (GHz)	30-40	70-100	>100
Noise Figure	~1	0.8	0.3[2]
Early voltage (V)	20	>60	>>100
Gain	Same for all 3: 50-150		

- **Table 1:** Summary comparison of SiGe, Si BJT and III-V technologies

Background: basic parameter

f_T : the cut-off frequency at which the current gain decay to unity or 0dB

$f_{\max}$: the cut-off frequency at which the power gain decay to unity or 0dB

Noise figure: The ratio of the output noise power of a device to the portion thereof attributable to thermal noise in the input termination at standard noise temperature (usually 290 K).

Early voltage: a measure of the base width modulation and should be as high as possible

$$Gain: \beta = \frac{I_C}{I_B}$$

Trade-off in classical BJT design

$$\beta = \frac{I_C}{I_B} \propto \frac{N_E}{N_B}$$

$$\frac{1}{2\pi f_T} = \tau_E + \tau_B + \tau_{BC} + \frac{kT}{qI_C}(C_{JE} + C_{JC}) + (R_E + R_C)C_{JC}$$

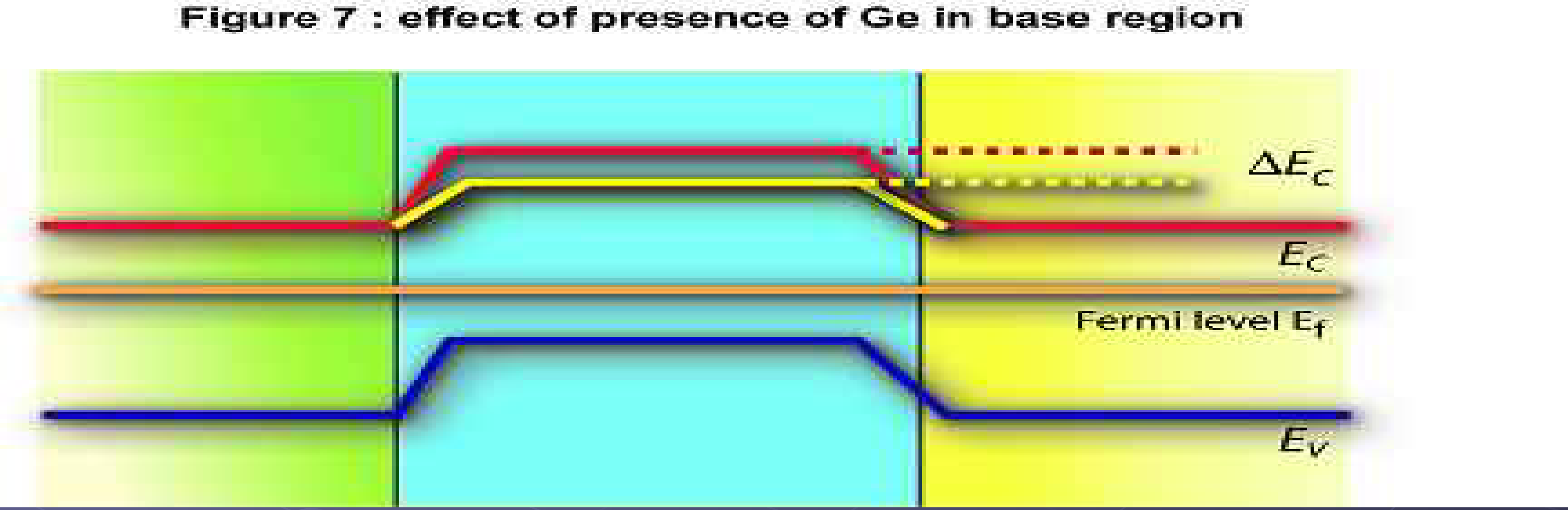
$$f_{\max} = \sqrt{\frac{f_T}{8\pi R_B C_{JC}}}$$

$$R_B \propto \frac{1}{W_B N_B}$$

we find ourselves in the frustrating situation where:

- We increase base doping to improve the noise factor but this degrades the gain.
- We narrow the base to improve the fT and this degrades the noise factor and the fMAX.
- We increase collector doping to improve the fT and we reduce the Early voltage and, if we go far enough, degrade fMAX.

Effect of Ge Doping in Base Regin



- The energy bandgap (EG) between conduction and valence bands in silicon is 1.1eV. Now that of germanium is 0.7eV. Quite simply, the addition of germanium reduces the band gap

Effect of Ge Doping in Base Regin

Up to concentrations of about 30%, the reduction in band gap is given by the relation known as **Vegard's law :**

$$\Delta E_C = 0.74[x]$$

where [x] is the germanium concentration.

So with say 10% Germanium (not far off typical) , we arrive at the bandgap reduction of ~0.07eV which seems hardly anything until we consider the relationship which relates collector current to bandgap :

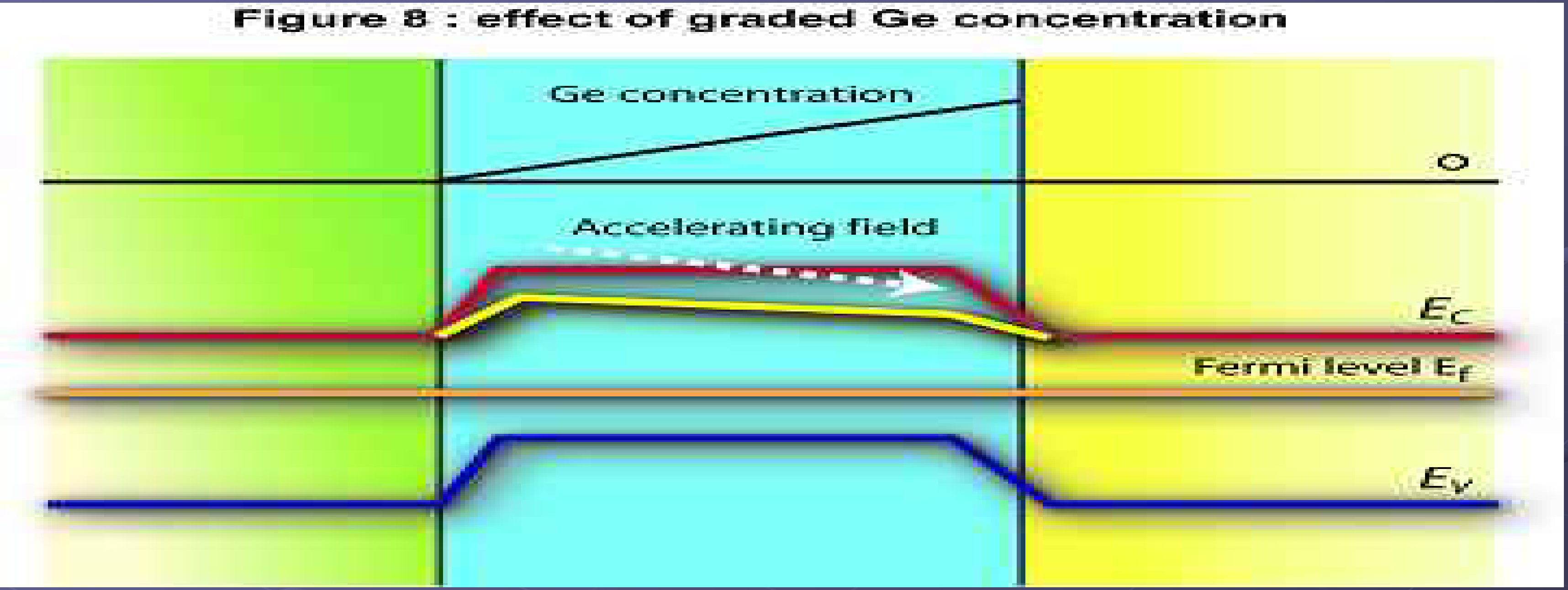
$$I_C \propto \exp \frac{-(E_{C\_base} - E_{C\_emitter})}{kT}$$

Compare the equations for with and without Ge and we get :

$$I_{C-SiGe} = I_{C-Si} \exp \frac{\Delta E_C}{kT}$$

Plugging in the numbers, we find a 10% addition of Ge multiplies the collector current by 30. However the base current has not changed because it is not affected by this phenomenon so the gain leaps by factor of 30. This is the principal effect of the germanium but not the only one.

Effect of Ge Doping in Base Regin



By grading the concentration of germanium in the base **(Figure 8)**, increasing it from emitter toward collector, we increase the   at the collector end. This has two nice effects:

- Of creating a pseudo field which accelerates the electrons across the base and therefore increasing fT and fMAX
- Of reducing the effect of collector bias on base narrowing; classical BJT's of fT's in the 25GHz often have Early voltages around 20 whereas SiGe HBT's with higher fT's reach values well over 60.

Conclusion

- From the physical perspective, we explain the effect of Germanium doping in BJT and how this effect enhances the performance in wireless communications.

- In short, the addition of Germanium permits a very large improvement in the gain without degrading other parameters.