A Comparative SiGe and InP HBT RF Reliability Study

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Outline

• Motivation and transistor characterization
• RF stress conditions and device degradation
• Summary and conclusion
Motivation and transistor characterization
Silicon-Germanium HBT

\[ V_{BC} = \{-0.5, -0.3, 0, 0.3\} \text{ V} \]

\[ f = 25 \text{ GHz} \]

\[
\begin{align*}
J_C \text{ (mA/\mu m}^2) & \quad 10^0 & \quad 10^1 & \quad 10^2 \\
V_{BE} \text{ (V)} & \quad 0.7 & \quad 0.8 & \quad 0.9 \\
\end{align*}
\]

\[
\begin{align*}
f_T \text{ (GHz)} & \quad 0 & \quad 100 & \quad 200 & \quad 300 \\
J_C \text{ (mA/\mu m}^2) & \quad 10^{-1} & \quad 10^0 & \quad 10^1 & \quad 10^2 \\
\end{align*}
\]

=> Very good agreement between HICUM/L2 simulation and measurement data
Indium-Phosphide HBT

\[ V_{BC} = \{-0.4, -0.3, 0, 0.3\} \text{ V} \]

\[ f = 20 \text{ GHz} \]

=> Very good agreement between HICUM/L2 simulation and measurement data
Open-base collector-emitter breakdown voltage $BV_{CEO}$

=> Same $J_C/J_{C,fT-peak}$ of respective HBT used to determine $BV_{CEO}$

$BV_{CEO}^{SiGe} < BV_{CEO}^{InP}$

=> Implications for RF reliability?

=> Compare RF degradation behavior of both devices
**Open-emitter collector-base breakdown voltage $BV_{CBO}$**

$BV_{CBO} = \begin{cases} 
3 & V_{BE} = 0 \\
2 & 0 < V_{BE} < 1 \\
1 & 1 < V_{BE} < 2 \\
0 & V_{BE} > 2 
\end{cases}$

SiGe

InP

$10^3 J_C/J_{C,f_{T,peak}}$ vs $V_{CB}$

$BV_{CBO}$ (SiGe HBT) $>$ $BV_{CBO}$ (InP HBT)

=> Same $J_C/J_{C,f_{T,peak}}$ of respective HBT used to determine $BV_{CBO}$
Self-heating-caused limitation of the maximum quiescent $V_{CE}$

$V_{BE} = \{0.8, 0.82, 0.84, 0.85, 0.86, 0.88, 0.9, 0.94\} \text{ V}$  
$V_{BE} = 0.78 \ldots 0.9 \text{ V}$ in 20 mV steps

$J_c (\text{mA}/\mu \text{m}^2)$ vs $V_{CE} (\text{V})$

$J_c (\text{mA}/\mu \text{m}^2)$ vs $V_{CE} (\text{V})$

$\Rightarrow$ Self-heating limits maximum attainable quiescent $V_{CE}$ at fixed $J_c$
RF stress conditions and device degradation
Silicon-Germanium HBT: RF stress conditions

\[ V_{CE} = 2 \text{V}, \quad f_0 = 10 \text{GHz}, \quad \Gamma_{L0} = 0.527/70.1^\circ \]
\[ J_{C,\text{lin}} = 6 \text{mA/\mu m}^2 \]

\[ \begin{align*}
P_{\text{avs}} &= \{-7.91, 1.13\} \text{dBm} \\
I_C &= 0 \times V_{BE} = 0
\end{align*} \]

\[ 10 \log_{10} \left( \frac{P_{L,\text{del}}}{A_{E0}} \right) \]

\[ P_{\text{avs}} (\text{dBm}) \]

\[ J_C, G_t, \text{PAE} \]

\[ \begin{align*}
I_C (\text{mA}) &\quad I_C (\mu A) \\
V_{CE} (\text{V}), v_{CE} (\text{V}) &\quad \Gamma_L = 0.527 \quad \angle 70.1^\circ
\end{align*} \]

\[ P_{\text{L,del}}/A_{E0}, \circ J_C, \bigtriangleup G_t, \times \text{PAE} \]

\[ \Rightarrow \text{Transient } i_C(t)-v_{CE}(t) \text{ swings far beyond } BV_{CEO} \text{ up to } v_{CE}(t) (\approx v_{CB}(t)) \approx BV_{CBO} \]
Silicon-Germanium HBT: Device degradation

\[ \delta r_{12} = \delta \text{Re}\{Z_{12}\} \approx \delta R_E \]

\[ J_C = [6\ldots40] \text{mA/\mu m}^2 \quad \frac{P_{L,\text{del}}}{A_{E0}} = [1.5\ldots31] \text{mW/\mu m}^2 \]

\[ J_C > 40 \text{mA/\mu m}^2 \quad \frac{P_{L,\text{del}}}{A_{E0}} > 31 \text{mW/\mu m}^2 \]

\[ \delta I_C = \{6\ldots40\} \text{mA/\mu m}^2 \quad \delta r_{12} = \delta \Re\{Z_{12}\} \approx \delta R_E \]

\[ V_{CE} = 0.7 \text{V} \quad J_C > 40 \text{mA/\mu m}^2 \quad P_{L,\text{del}} > 31 \text{mW/\mu m}^2 \]

\[ \times 0.81 \text{V} \quad \bigcirc 0.85 \text{V} \quad \triangle 0.92 \text{V} \]

\[ \times 0.96 \text{V} \quad \bigcirc 1.00 \text{V} \]

\[ t_{\text{stress}} (h) \]

=> Significant degradation only in highly non-linear RF operation

=> Degradation behavior qualitatively similar to SG13G2
Indium-Phosphide HBT: RF stress conditions

\[ V_{CE} = 2.5 \text{ V}, \quad f_0 = 10 \text{ GHz}, \quad \Gamma_{L0} = 0.674 / 29.3^\circ \]
\[ J_{C,\text{lin}} = 6 \text{ mA/\mu m}^2 \]

\[ P_{\text{avs}} = \{-7.91, 0.13\} \text{ dBm} \]

\[ *V_{BE} = 0.82 \text{ V} \quad \circ I_B = 0 \]

\[ \Rightarrow \text{Transient } i_C(t) - v_{CE}(t) \text{ up to } v_{CE}(t) (\approx v_{CB}(t)) \approx B V_{CBO} \approx B V_{CEO} \]
RF stress conditions and device degradation

**Indium-Phosphide HBT: Device degradation**

\[ \delta r_{12} = \delta \text{Re}\{Z_{12}\} \approx \delta R_E \]

- \[ J_C = [6 \ldots 8] \text{ mA/\mu m}^2 \]
- \[ P_{L,\text{del}} = [3.7 \ldots 7.3] \text{ mW/\mu m}^2 \]

\[ V_{CE} = 0.7 \text{ V} \]

\[ J_C = 9.3 \text{ mA/\mu m}^2 \]

\[ \frac{P_{L,\text{del}}}{A_{E0}} = 7.8 \text{ mW/\mu m}^2 \]

\[ \delta r_{12} = \delta R_E \{Z_{12}\} \approx \delta R_E \]

- \[ J_C = [6 \ldots 8] \text{ mA/\mu m}^2 \]
- \[ P_{L,\text{del}} = [3.7 \ldots 7.3] \text{ mW/\mu m}^2 \]

\[ J_C = 9.3 \text{ mA/\mu m}^2 \]

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=> Significant degradation only in highly non-linear RF operation
**InP HBT: Reproduction of degradation behavior**

\[
\delta r_{12} = \delta \text{Re}\{Z_{12}\} \approx \delta R_E
\]

\[V_{CE} = 0.7 \text{ V}\]

\[
J_C = 9.3 \text{ mA/\mu m}^2 \quad \frac{P_{L,\text{del}}}{A_{E0}} = 7.8 \text{ mW/\mu m}^2
\]

\[
\delta I_C\% = \frac{I_C(t) - I_C(0)}{I_C(0)} \times 100\%
\]

\[
\delta r_{12}\% = \frac{r_{12}(t) - r_{12}(0)}{r_{12}(0)} \times 100\%
\]

=> Degradation behavior reproducible on a different die
Summary and conclusion
Summary and conclusions

• The investigated SiGe and InP HBTs are extremely robust and reliably operable far beyond $BV_{CEO}$ during the investigated stress times.

• It is very difficult to measure degradation of SiGe HBTs under the most extreme dynamic stress conditions.

• Only strongly non-linear RF operation causes degradation of the collector current in both devices under test during the investigated stress times.

• In contrast to SiGe HBTs, the emitter resistance in InP HBTs degrades noticeably as well.

• The smaller $BV_{CEO}$ of SiGe HBTs (compared to InP HBTs) does not have any negative implications for RF reliability.
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