HEMTs and HBTs: Devices, Fabrication, and Circuits

Fazal Ali
Pacific Monolithics

Aditya Gupta
Westinghouse Electric Company

Editors

Artech House
Boston • London
Contents

Preface xi

Chapter 1 HEMTs and HBTs: Introduction and Overview  Fazal Ali and Aditya Gupta 1
1.1 Introduction 1
1.2 High Electron Mobility Transistors (HEMTs) 3
1.3 Heterojunction Bipolar Transistors (HBTs) 5
1.4 Summary 8

Chapter 2 HEMT Device Physics and Models Mukunda B. Das 11
2.1 Introduction 11
2.2 Carrier Transport in the HEMT Structure 13
2.2.1 Band Diagram and 2-DEG in AlGaAs/GaAs Systems 14
2.2.2 2-DEG Carrier Mobility and Saturation Velocity 18
2.2.3 2-DEG Charge-Control by Schottky Barrier Gate 22
2.2.4 Ohmic Contacts and Series Resistances 26
2.3 The Charge-Control Model 29
2.3.1 dc and Small-Signal Characteristics 29
2.3.2 Temperature Stability of Device Operation 36
2.3.3 Low-Frequency (LF) Equivalent Network Model 39
2.3.4 The Unity-Current-Gain Frequency 44
2.3.5 Low-Frequency 1/f and g-r Noise Sources 47
2.4 High-Frequency (HF) Limitations 51
2.4.1 HF Equivalent Network for the Intrinsic HEMT 52
2.4.2 Determination of Equivalent Network Parameters 57
2.4.3 Power Gain and Stability 61
2.4.4 HF Noise Sources and Performance of HEMTs 63

Chapter 3 HEMT Devices and Circuit Applications  P.C. Chao, Alan Swanson, April Brown, Umesh Mishra, Fazal Ali, and Cindy Yuen 77
4.4 High Frequency Limitations 224
   4.4.1 HF Two-port Parameters and Equivalent Network Model 224
   4.4.2 Determination of the Equivalent Network Parameters 228
   4.4.3 Power Gain and Stability 234
   4.4.4 HF Noise Sources and Noise Figures 236
   4.4.5 Power Density Limitations of HBTs 241
   4.4.6 Comparison of HBTs and HEMTs 246

Chapter 5 HBT Devices and Circuit Applications 253
   Michael E. Kim, Burhan Bayraktaroglu, and Aditya Gupta
   5.1 Introduction 253
      5.1.1 Comparison with GaAs MESFET and HEMT 257
      5.1.2 Comparison with Advanced Silicon Bipolar Transistor 258
   5.2 Device Structure 260
      5.2.1 Epitaxial Layer Growth 266
      5.2.2 Emitter-up versus Collector-up 269
   5.3 HBT Fabrication Technology 270
      5.3.1 Self-Aligned Contacts 274
      5.3.2 Planar Structures 276
      5.3.3 Representative HBT IC Process 278
   5.4 Technology Characterization 281
      5.4.1 HBT dc Characteristics 282
      5.4.2 HBT High-Frequency Characteristics 286
      5.4.3 Intrinsic HBT Linearity 287
      5.4.4 Intrinsic HBT Nonlinearity 287
      5.4.5 HBT Noise Performance 290
      5.4.6 Schottky Diode Characteristics 291
      5.4.7 Thin-Film Resistors 291
      5.4.8 Metal-Insulator-Metal (MIM) Capacitors 292
      5.4.9 HBT Device Modeling and Simulation 292
      5.4.10 Technology Qualification 292
   5.5 Power HBT Design Considerations 301
      5.5.1 Collector Design 301
      5.5.2 Device Impedance 302
      5.5.3 Size Considerations 304
      5.5.4 Thermal Considerations 307
      5.5.5 HBT Scaling 311
      5.5.6 HBT Monolithic Amplifiers 316
      5.5.7 HBT Complementary Amplifiers 318
   5.6 Circuit Applications 322
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.6.1</td>
<td>Analog and Microwave Applications</td>
<td>328</td>
</tr>
<tr>
<td>5.6.2</td>
<td>Microwave Oscillators</td>
<td>333</td>
</tr>
<tr>
<td>5.6.3</td>
<td>Digital Applications</td>
<td>341</td>
</tr>
<tr>
<td>5.6.4</td>
<td>Analog-to-Digital Conversion Applications</td>
<td>345</td>
</tr>
<tr>
<td>5.6.5</td>
<td>Monolithically Combined Microwave-Digital Applications</td>
<td>352</td>
</tr>
<tr>
<td>5.7</td>
<td>InP-Based HBT</td>
<td>354</td>
</tr>
<tr>
<td>5.8</td>
<td>Reliability</td>
<td>361</td>
</tr>
<tr>
<td></td>
<td>Index</td>
<td>371</td>
</tr>
</tbody>
</table>