Measurement Techniques for Radio Frequency Nanoelectronics

Connect basic theory with real-world applications with this practical, cross-disciplinary guide to radio frequency measurement of nanoscale devices and materials.

- Learn the techniques needed for characterizing the performance of devices and their constituent building blocks, including semiconducting nanowires, graphene, and other two-dimensional materials such as transition metal dichalcogenides.
- Gain practical insights into instrumentation, including on-wafer measurement platforms and scanning microwave microscopy.
- Discover how measurement techniques can be applied to solve real-world problems, in areas such as passive and active nanoelectronic devices, semiconductor dopant profiling, subsurface nanoscale tomography, nanoscale magnetic device engineering, and broadband, spatially localized measurements of biological materials.

Featuring numerous practical examples, and written in a concise yet rigorous style, this is the ideal resource for researchers, practicing engineers, and graduate students new to the field of radio frequency nanoelectronics.

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"This book represents a state-of-the-art look at measurement techniques of nanoelectronic devices in the RF and microwave frequency range. This field is of growing importance because of higher CMOS clock speeds approaching the GHz range as well as shrinking device dimensions, down to the 10 nm scale and below. The fundamental physical challenges of measuring and characterizing devices with these length scales, which approach atomic dimensions, are clearly laid out and presented in this book. The book begins with fundamental network analysis theory based on Maxwell's equations for radiation and transmission lines, progresses to on-wafer semiconductor device characterization in the RF and microwave to mm-wave frequency range, and progresses to apply these fundamentals to an increasingly challenging set of measurements. High impedance devices (up to and greater than the resistance quantum) are covered in detail, with the latest on-wafer calibration procedures laid out clearly. Scanning microwave microscopy as a complementary technique for high impedance devices is also covered. Materials characterization, including the beginnings of a new field of scanning microwave microscopy for tomography (a nanoscale version of synthetic aperture radar), is also covered. Applications to nanowires, nanotubes, and 2D materials such as graphene and WS2, in both passive and active modes, are clearly presented. I expect this book will be of great interest to beginning graduate students and senior undergraduates entering the field, as well as senior researchers with an interest in the latest techniques for measuring these tiny devices, which tend to have high impedances due to the quantum nature of electricity at this atomic length scale."

Peter Burke, University of California, Irvine

"This is a remarkable reference on high frequency nanoelectronics measurements and scanning microwave microscopy that includes applications for nano-devices and advanced materials. The basics of radio frequency (RF) measurements for extreme impedances and nanoscale-sized RF probes are laid out very well, as well as advanced concepts in modeling and RF calibration. This accessible book will be useful for a wide readership, including researchers and students in microwave engineering, semiconductor electronics, materials science, and microscopy."

Ferry Kienberger, Keysight Laboratories, Keysight Technologies Inc.

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Abbreviations

2DEGs	Two-dimensional electron gases
AFM	Atomic force microscopes
AM-EFM	Amplitude-modulated, electrostatic force microscopy
CNT	Carbon nanotubes
CPW	Coplanar waveguide
DOS	Density of states
DUT	Device under test
EPR	Electron paramagnetic resonance
ESR	Electron spin resonance
FEM	Finite-element modeling
FET	Field effect transistors
FMR	Ferromagnetic resonance
GaN	Gallium nitride
GPR	Ground penetrating radars
GS	Ground-signal
GSG	Ground-signal-ground
LRM	Line-reflect-match
LRRM	Line-reflect-reflect-match
MEMS	Microelectromechanical systems
MESFET	Metal semiconductor field effect transistor
MFM	Magnetic force microscope
MIS	Metal-insulator-semiconductor
MOS	Metal-oxide-semiconductor
MRFM	Magnetic resonance force microscopy
NMR	Nuclear magnetic resonance
NSMM	Near-field scanning microwave microscope
NSOM	Near-field scanning optical microscopy
PALM	Photoactivated localization microscopy
RF	Radio Frequency
SCM	Scanning capacitance microscope
SEM	Scanning electron microscope
SiO_2	Silicon dioxide
SKPM	Scanning kelvin probe microscope

SOLT	Short-open-line-thru
SSRM	Scanning spreading-resistance microscope
STED	Stimulated emission depletion
STM	Scanning tunneling microscope
STS	Scanning tunneling spectroscopy
SUT	Sample under test
TE	Transverse electric
TEM wave	Transverse electromagnetic wave
TIRF	Total internal reflection fluorescent microscopy
TM	Transverse magnetic
TMD	Transition metal dichalcogenides
TRL	Thru-reflect-line
VED	Vertical electric dipole
VNA	Vector network analyzer
YIG	Yttrium iron garnet