RF Substrate Technologies
for Mobile Communications
White paper

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Abstract
This white paper discusses a variety of RF materials and substrates capable of meeting RF Front-End module designers' requirements.
You will gain insight into how state-of-the-art expertise in substrate technology can enable the mobile devices of the next decade.

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Introduction

In today's connected world, the demand for mobile communications and instant access to information, anytime and anywhere, has drastically changed the consumer electronics landscape. Infrastructure, mobile handsets, tablet computers and other aspects of portable communications are all seeing unprecedented growth in the amount of data being exchanged. With this boom in activity, semiconductor technology – from substrate materials to installed devices – must be optimized to maximize the cost/benefits ratio.

The mobile communications segment of the global consumer electronics market is growing at unprecedented speed *(Figure 1),* and the companies reaping the biggest rewards are those that can deliver innovative capabilities and higher circuit performance. Selecting the right semiconductor substrate technology can provide a strategic advantage by achieving higher performing application processors, baseband, memory, imagers, microphones, screens and more. Mobile RF components – specifically radio-frequency front-end (RFFE) modules – provide a good case study of how to leverage substrate technology.

In this paper, we will discuss a variety of RF materials and substrates capable of meeting designers' requirements. You will gain insight into how state-of-the-art expertise in substrate technology can enable the mobile devices of the next decade.

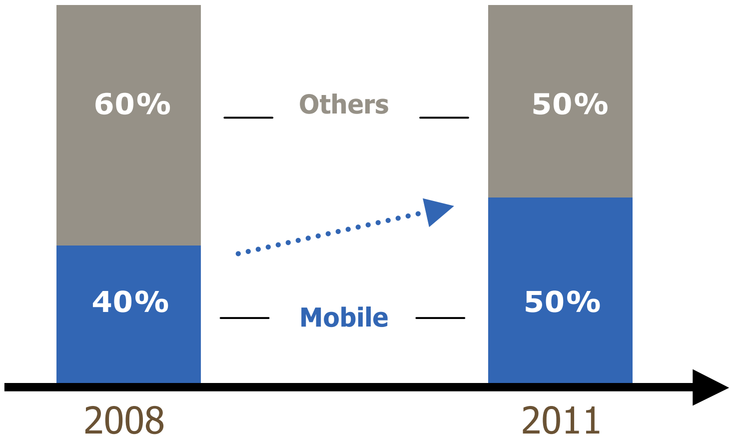


Figure 1: The growth of mobile devices as a percentage of the global consumer electronics market (Source: GFK/CEA)

RF basics and issues

Driven by market demand to access and exchange multimedia content, cellular networks need to continuously improve their data-rate capabilities. The emerging Long Term Evolution system (LTE, also called 4G) is targeting data rates in excess of 300 Mb/s, closing the gap with existing wireless 802.11n systems. To enable this high data-transfer speed, the allowed bandwidth is dramatically increasing. For example, the U.S. Federal Communications Commission is planning to open 500 MHz of bandwidth by 2015, spread over a few hundred megahertz to 4 GHz.

This infrastructure growth raises many questions. How can these new bands be supported? How can carrier aggregation be handled? How can roaming be efficiently managed? Which architectures and technologies will be selected to enable such a system?

A predictable change is the convergence of both cellular and connectivity systems. But would it be advantageous to integrate both systems in the same chipset? And if so, which chip architecture and semiconductor technologies will present the best solution?

To meet today's RF performance requirements, most mobile devices contain eight or more integrated circuits and modules. Some of these chip sets use several different substrate technologies. In the past, the standard approach to handling new RF communication standards while ensuring backward compatibility was to add a module for each new RF standard or new RF bands. This inefficient approach has reached its limit, leading the manufacturers of communication products to find a more suitable integration path.

In today's mobile systems, RF functionalities can be split into two main blocks: transceivers and RFFE modules. Both approaches have specific characteristics, depending on the targeted application. The main difference is the partitioning between digital and analog functionality. In a transceiver, the balance is 80% digital and 20% analog, while the inverse ratio is found in a RFFE module.

Key functions of RFFE modules

RFFE modules enable reception and transmission of RF signals to travel back and forth from the transceiver circuit to the antenna. *Figure 2* shows a block diagram of a typical RFFE module's transmit signal path. Switch, power amplifier, power management unit and filter are key functional blocks. Other functions such as power sense coupling or planned new capabilities including antenna tuning are also integrated.

The RFFE module's primary purpose is to optimize the performance of wireless networks and handsets at the lowest possible operating cost.

Figure 2: An RFFE module's transmit signal path

Block	Function	Key Spec	System Impact
Switch	Connect Rx & Tx to right ports	Linearity Insertion loss	Data rate System Coexistence Range
Power Amplifier	Amplify Transceiver Tx	Power Added Efficiency Max Output Power Linearity	Battery life Range Data rate System coexistence
Power Mgt Unit PMU	Supplies & control signals generation	Regulation efficiency Tunability	Battery life
Filter	Filter out of band noise & signals	Quality factor Temperature stability	Sound quality Background noise System coexistence

Figure 3: RFFE module functions and key specifications

Selecting the optimal substrate

In 3G and 4G cellular standards, the performance requirements for networks and handsets are quite stringent. As shown in *Figure 4*, the process technologies and substrates used can vary from one key function to another. Even if price is a factor, performance pushes RFFE module manufacturers to choose the optimum substrate and process technology for each function. Most of the leading module makers use an advanced multi-chip module approach.

Block	Key device parameter	Key substrate parameter	2011 market technology of choice
Switch	Breakdown voltage Ron, RF loss	Linearity Resistivity	GaAs pHEMT, SoS, HR-SOI
Power Amplifier	Gain, Ft Current Density Breakdown voltage	Carrier mobility Thermal dissipation Linearity Resistivity	GaAs HBT, LDMOS
Power Mgt Unit	Ron Current density Breakdown voltage CMOS enable	Thermal dissipation	HV CMOS
Filter	Q(L), Temp stability, Coupling coefficient	Resistivity Piezoelectricity	SAW, BAW, IPD, smd

Figure 4: RFFE modules incorporate a variety of technologies

Figure 4 shows the technology of choice in 2011 for each module function. These choices may change in the future with the evolution of new communications systems and advances in process technologies and substrates.

Regarding performance, *Figure 5* shows the target properties of the ideal materials and processes. Let's examine the current state of the available technologies.

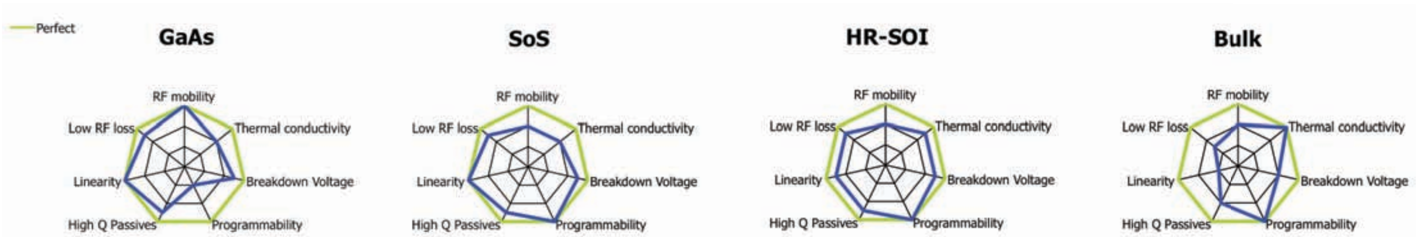


Figure 5: Substrate and process performance versus ideal target

Gallium arsenide (GaAs)

Gallium arsenide (GaAs) offers the highest RF mobility, making it the substrate material of choice for millimeter wave-frequency applications. GaAs also is a state-of-the-art material for low-noise amplifier structures due to its high breakdown voltage, low RF loss and high linearity.

Designs to meet 4G specifications are under development, including innovative architectures, improved processes and higher resolution lithography. There are basically two deposition technologies to grow GaAs devices: molecular beam epitaxy (MBE) and metal organic chemical vapor deposition (MOCVD). MBE is an extremely precise method allowing the films to grow epitaxially.

Regarding applications in RF systems, GaAs is facing some limitations in terms of digital integration. This is leading to GaAs solutions coupled to CMOS circuits. In response to this integration trend, new GaAs processes such as BiFET or BiHEMT are being developed to enable grouping of different functions on a single die for RFFE module integration *(References 1 and 2).*

Silicon-on-sapphire (SoS)

Silicon-on-sapphire (SoS) substrates are well suited for RF applications and provide outstanding performance. Furthermore, they can co-integrate digital and RF functions to produce the RF functionalities and high digital content needed to build highly programmable systems.

SoS substrates are well recognized for delivering the best performance switches. As shown in *Figure 5*, this material has all the performance attributes needed for RFFE module integration, combining power amplifiers, switches and antenna tuning on a single chip *(References 3 and 4).*

Two types of these substrates are available: epi SoS (reference 13) and bonded SoS. Bonded monocrystalline SOS is built using transfer processes and direct wafer-bonding expertise to transfer and bond a high-quality, thin silicon layer onto a sapphire substrate. The resulting bonded silicon layer offers impressive improvements in transistor mobility and silicon quality beyond conventional SoS wafers, which utilize an epitaxially grown silicon layer. The substrate provides an ideal design landscape for enhanced RFIC performance, functionality and form factor, enabling IC size reduction while increasing performance by as much as 30 percent.

High-resistive silicon-on-insulator (HR-SOI)

As shown in *Figure 5*, HR-SOI satisfies all RF performance requirements. Continuous substrate improvements in addition to process and substrate options were developed to further improve the RF capability of this technology *(References 5-8)*. The thermal conductivity of HR-SOI can be addressed with a proper thermal strategy or box engineering. Like SoS, this technology opens the door to full RFFE module integration, including multiple functions on one chip *(Reference 9).*

HR-SOI combines the extremely good performance of SOI for isolating signal from noise while insuring signal power integrity. It also shows a good insertion loss and brings the same programmability level as a standard silicon bulk substrate.

Silicon bulk

Finally, bulk substrates present a good compromise solution for systems requiring high digital integration and standard RF performances.

The major issues with silicon bulk substrates and their RF properties are poor linearity and high RF signal loss (*Figure 5*). Using triple wells and high-resistive bulk *(Reference 10)* are options to improve those parameters, but making switches remains extremely challenging. The semiconductor industry has spent the past decade trying to make power amplifiers using silicon bulk substrates and standard CMOS processes *(References 11 and 12)*. But performance parameters such as voltage handling, passives quality, mobility and high RF loss raise many challenges in designing high-performance power amplifiers. Bulk CMOS is mainly used for chips requiring high digital processing integration, such as combination chips or transceivers. LDMOS is a reference technology for PA used in base stations (high power PA) and also has some traction in the handset PA market.

Conclusion

The advent of the 4G cellular system and the convergence of cellular and connectivity systems present many challenges. But there are some promising technological solutions that can achieve the needed performance while also being suitable for high-volume manufacturing to meet the needs of the booming consumer electronics market.

Developing an integrated solution – combining performance, area and cost – requires a production-proven substrate technology. With the market demanding continual innovation and new capabilities in mobile devices, the communications industry needs reliable fabrication processes and substrates that can accommodate new designs and advanced features.

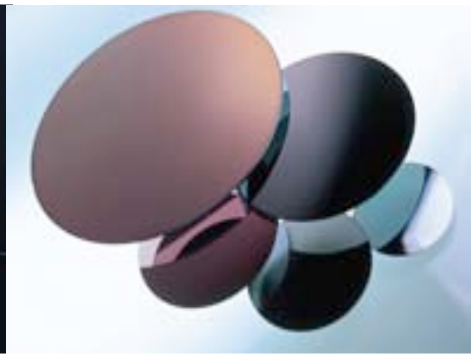
Soitec's combined expertise in process technology, substrate materials and high-volume manufacturing represents a compelling roadmap to support device manufacturers in achieving both incremental improvements and breakthrough innovations in mobile communications. Our mature materials technologies including Smart Cut™ and Smart Stacking™, III-V epitaxy and laser lift off enable structures with multiple layers or even stacked circuits. So whatever type of product strategy an RF manufacturer is pursuing, Soitec has the substrate technology to produce components with higher RF performance and lower costs.

Smart Cut™ is Soitec's proprietary technology to transfer a thin layer of crystalline material from a donor wafer to another substrate.

Smart Stacking™ is a wafer-to-wafer technology platform that enables very thin layers of partially or fully processed wafers to be transferred onto other wafers (Reference 14).

Soitec GaAS Epi

Soitec Bonded SoS



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About Soitec

Soitec (Euronext Paris) is an international manufacturing company, a world leader in generating and manufacturing revolutionary semiconductor materials, at the frontier of the most exciting energy and electronic challenges. Soitec's products encompass substrates for micro and nanoelectronics (most notably SOI: Silicon-On-Insulator) and concentrating photovoltaic systems (CPV). The company's core technologies are Smart Cut™, Smart Stacking™ and Concentrix™, as well as expertise in epitaxy. Soitec delivers enhanced performance and energy efficiency to a broad range of applications including consumer and mobile electronics, microelectronics-driven IT, telecommunications, automotive electronics, lighting products and solar power plants for large scale utilities. Soitec has manufacturing plants and R&D centers in France, Singapore, Germany, and the United States.

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