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Using SiGe HBTs for Mixed-Signal Circuits and Systems: Opportunities and Challenges

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A Compelling Story

SiGe HBT technology, by any fair accounting, must be judged a remarkable success story. From the first demonstration of a (barely) functional SiGe HBT in December of 1987, until the achievement of the present performance record of 375 GHz peak f_T in December of 2002, a mere 15 years has elapsed. SiGe technology has evolved from simple device and circuit demonstrations in a select few research laboratories to robust production in upwards of two-dozen manufacturing facilities around the world (and growing), and commercial products abound across a wide spectrum of commercial applications. Time flies. In this paper I will: review the state of SiGe HBT technology, with an emphasis on some of the emerging industry trends; cast a light on some new application developments and opportunities; offer a personal view of the major open issues and concerns for the future; and make some concluding remarks on performance limits.

It is my personal view (clearly I'm not unbiased!) that SiGe technology, in its most commonly practiced, full BiCMOS form, has the potential to change the way we will conceive, implement, and ultimately deploy the emerging global wired and wireless communications infrastructure which will be required to support the needs of 21st century. Bold words. Let me elaborate.

Industry Trends

SiGe HBT technology is clearly becoming fairly routine to execute on a mature manufacturing line, using a variety of epi growth techniques, particularly if one limits performance to about 50 GHz peak f_T (1st generation). At the 100 GHz performance level (2nd generation), there are upwards of ten industrial "players" to date, and even at the 200 GHz (3rd generation), there have been five companies (at last count) on the road to manufacturing (two are almost there [1]). Paths to foundry services on multiple technology platforms exist, thus enabling many groups (both industrial and academic) to begin to dabble with the potential leverage that SiGe can offer. The recent flood of record-setting circuit results have been impressive to behold (almost 10% of the papers at this year's ISSCC were SiGe), and is starting to snowball. Competitive products in application areas historically taboo to Si/SiGe (e.g., power amplifiers for cell phones) are being reported as we speak. These are exciting times in our field. SiGe continues to marginalize GaAs (and InP) for most non-photonic applications. Clearly, CMOS continues to march onward, but the superior performance of the SiGe HBT across a broad array of metrics, and the time-to-market leverage this potentially offers, bodes well for the future.

New Developments and Opportunities

Recent research on unique applications of SiGe HBTs offer intriguing opportunities for an expanded product application space for the future. These arenas include: 1) complementary SiGe (npn + pnp SiGe HBTs) for high-speed analog circuits [2], 2) monolithic mm-wave applications (e.g., the 60 GHz ISM band) for short-range, very high data rate wireless links (1 Gb/sec) [3], 3) monolithic radar systems for both defense and commercial (e.g., collision radar) applications, and 4) operation of ICs in extreme environments, including: cryogenic temperatures (to 77K and below), high temperatures (to 300°C), and in radiation-rich environments (e.g., space) [4]. Even contemplating such applications with a Si-compatible IC technology was grounds for ridicule (and maybe laughter!) as recently as a year or two ago. Yet, proof-of-concept demonstrations are being routinely reported today. As will be shown, SiGe HBT technology offers compelling virtues for each of these emerging application fronts.

Open Issues and Concerns

Despite what one may hear to the contrary, by no means should SiGe HBTs be considered a fully-mature subject which is completely understood. Many open questions abound [5], including: 1) the need for better values for fundamental parameters in SiGe, 2) many issues related to film stability, and 3) isolation and pattern density induced stress effects. In addition, looming concerns associated with: 1) new types of device reliability degradation mechanisms [6], 2) scaling-induced variations in low-frequency noise performance [7], 3) a variety of intriguing breakdown issues and bias instabilities [8], 4) self-heating phenomena, and 5) the enormous current densities that SiGe HBTs must support, all represent valid concerns worthy of focused research.

Performance Limits

Just how far can one go with SiGe? This question is hotly debated [9], but the current record remains an extremely impressive 375 GHz [10]. Why not be bold. A fully-integrated, BiCMOS-compatible, ½ Terahertz (>500 GHz) SiGe HBT with >1.5V breakdown voltage will be demonstrated within the next 3 years. This level of performance has in fact already been achieved at cryogenic temperatures [11]. Stay tuned.

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