Nanotechnology for high frequency communications: nitrides and graphene

Fernando Calle[1] and Tomás A. Palacios[2]

[1]ISOM and Dept. Ingeniería Electrónica, ETSI Telecomunicación, Universidad Politécnica de Madrid
Campus de Excelencia Internacional Moncloa. Avda. Complutense 30, 28040 Madrid, Spain
[2]Dept. Electrical Engineering and Computer Science, Massachusetts Institute of Technology
77 Massachusetts Ave., Bldg. 39-567B, Cambridge, MA 02139
fernando.calle@upm.es

The achievement of higher frequencies (HF) and the reduction of energy consumption, to improve sensing, communication and computation, involve the continued scaling down to the nanometer level. This scaling is enabled by of innovative device designs, improved processing technologies and assessment tools, and new material structures. In this work, we have used all these factors to demonstrate state-of-the-art HF devices in two materials with quite different electronic properties: wide semiconductor bandgap III-nitrides for resonators and power amplifiers; and graphene, a zero bandgap material expected to revolutionize low noise and HF flexible electronics. Some issues faced during their development will be discussed during the talk.

Surface acoustic wave (SAW) devices are required for radar systems and wireless communications, as well as for high performance sensors. These SAW devices consist of an interdigitated transducer (IDT) on a piezoelectric substrate with a large sound velocity. To enhance their frequency, we exploit the combination of a compact IDT fabricated with e-beam lithography, the highest sound velocity provided by a diamond substrate, and the confined Sezawa modes in a thin AlN piezoelectric layer deposited on top. Both the IDT period and the film thickness are key parameters in the design and fabrication of the devices. The sputtering deposition of the piezoelectric layer on micro and nanocrystalline diamond and the lithography of the transducers are optimized. HF SAW resonators operating in the 10-20 GHz range (Fig. 1), showing up to 40 dB out-of-band rejection and Q factors larger than 10,000 are demonstrated [1]. Pressure sensors have also been developed on free standing AlN/diamond membranes.

The huge power density of AlGaN/GaN high electron mobility transistors (HEMTs) has brought during the last decade new possibilities and advantages for the design of wide and multiband amplifiers. High power-gain cutoff frequency (f_{max}) has been achieved by combining low-damage gate-recess technology, scaled device geometry, and recessed source/drain ohmic contacts to enable minimum short-channel effects (i.e., high output resistance R_{ds}) and very low parasitic resistances [2]. SiC substrates are required to minimize self-heating, as shown in Fig. 2(a). Some challenges for long-term reliability and device scaling, due to the strain induced by the large lattice mismatch between the AlGaN barrier and the GaN buffer, may be solved using the lattice-matched InAlN/GaN heterostructure. L_G=30 nm InAlN/GaN HEMTs on a SiC substrate with a record f_T in excess of 300 GHz were obtained by applying an oxygen plasma treatment [3]. The thin oxide layer on the InAlN surface suppressed the gate leakage current, passivated the surface, and significantly improved the RF performance. Further efforts are dedicated to identify the limiting factors and dominant failure mechanisms to improve GaN-based HEMT reliability, in particular heat spreading, by means of diamond layers and other C-based materials such as graphene and nanotubes.

Graphene is a carbon, one-atom-thick layer, the thinnest but strongest material in the world. It is a zero bandgap semiconductor with a room-temperature electron and hole mobility above 100,000 cm^2/V.s. A multidisciplinary effort among physicists, chemists, material scientists and device engineers has led to new electronic devices and circuits taking advantage of its unique properties. Some examples include RF multipliers, mixers, modulators and demodulators [4] (see fig. 3). Several technological issues during graphene devices processing (including growth technique, substrates, electrical isolation, contamination and passivation, etc. [5]) will be discussed.

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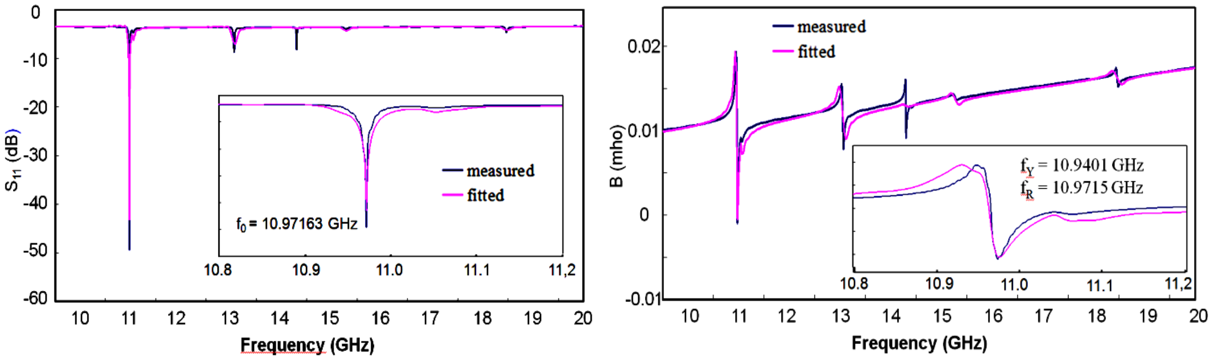
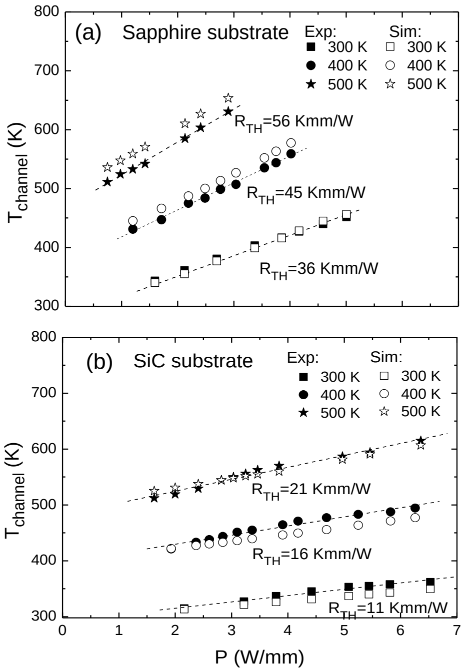


Figure 1. Measured and simulated reflection coefficient (S_{11}) (top) and susceptance (bottom) for λ=800 nm one-port SAW resonators on a 600 nm thick AlN film on diamond. Several resonances corresponding to Sezawa modes are observed.



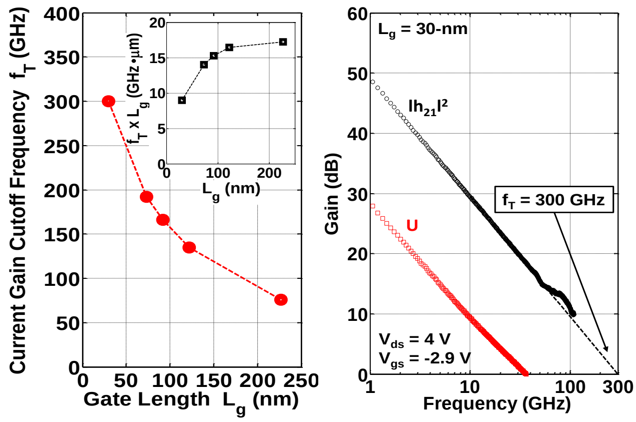
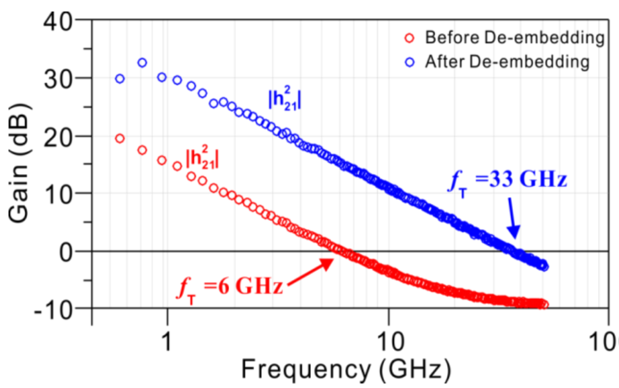


Figure 2. Left: $T_{channel}$ *vs* output power for different T_{amb} in devices grown on sapphire (a) and SiC (b). Right: RF performance of the 30-nm-gate-length InAlN/GaN HEMT with f_T = 300 GHz. (From [3]).



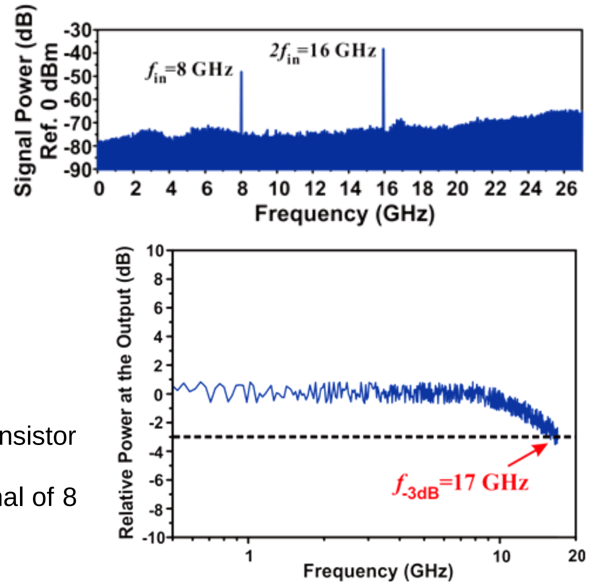


Figure 3. Left: First BN/Graphene/BN field effect transistor with L_G=400 nm.
Right: Output power of a HF doubler for an input signal of 8 GHz (top), and gain frequency response (bottom).