Novel Trends in Interface Engineering for Wide Band Gap (SiC and GaN) power devices

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Nowadays, the world energy consumption is expected to grow by nearly 50% until 2050, with a 30% increase in the electricity demand in the next decade. Hence, in order to guarantee a sustainable future for our society, a better power management and a more efficient use of the energy have become mandatory. In this context, the development of new semiconductor technologies for power electronics, providing a better efficiency with respect to silicon (Si), is a key enabler for the sustainability transition. Wide band gap (WBG) semiconductors, such as silicon carbide (SiC) and gallium nitride (GaN), are the ideal choice for the next generation of efficient power electronic devices. In fact, they provide excellent physical and electronic properties, and better performances with respect to Si devices in terms of breakdown voltage, on-resistance, leakage current, maximum temperature operation, etc. [1,2]. Hence, SiC and GaN are gradually pervading strategic market sectors, in which high efficient components are required, e.g. consumer electronics, automotive, transportations, energy conversion in renewable energies, etc.

Diodes and transistors are elementary active components of all energy conversion systems in power electronics. In particular, SiC- and GaN-based discrete devices are already commercialized in a variety of products, including Schottky diodes, Junction Barrier Schottky (JBS) diodes, Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) and High Electron Mobility Transistors (HEMTs) (see Fig. 1a). While today SiC and GaN devices have reached a notable technological maturity, leading to the replacement of the traditional Si power components in many applications, the need to push WBG semiconductors towards their ideal limits is currently the driving force for further technological breakthroughs [3]. In this context, metal/semiconductor and insulator/semiconductor interfaces are key parts, requiring to be accurately engineered to achieve the desired devices performances.

In this talk, some recent achievements of CNR-IMM group will be presented as case studies of novel interface engineering approaches to improve SiC and GaN unipolar devices performances.

Regarding 4H-SiC, a full control of the Schottky barrier height is a challenging issue, since the work function of common metals cannot be varied over a wide range. In addition, some of the commonly used metals (e.g. Ti, Ni) are extremely susceptible to react with SiC upon annealing. Hence, novel solutions based on refractory metallic compound are under investigation. In particular, the use of tungsten-based systems (e.g. WC) can be a promising solution to achieve low Φ_B values (lower than conventional Ti barrier) with a thermal stability up to 700°C [4] (see Fig. 1b). Moreover, it has been recently shown that a controlled reduction of the Schottky barrier height can be achieved also either through the local n-type heavy doping at the metal/SiC interface [5,6], as well as by non-conventional "sulfurization" surface treatments leading to Fermi level pinning effects [7].

In the case of 4H-SiC MOSFETs, nitridation processes in N_2O or NO of the SiO_2/SiC interfaces are commonly used to reduce the interface state density and, hence, increase the channel mobility. However, the presence of carbon-related defects due to interface re-oxidation effects can be detrimental for both the channel mobility and the device threshold voltage stability [8]. Hence, the fine control of the post-deposition annealing time is required to optimise the MOSFET interfacial transport and mitigate the threshold voltage instability [9]. In this context, the latest frontier in engineering the insulator/SiC interface in SiC MOSFET technology is the introduction of novel high-k dielectrics [10]. In this case, while Al_2O_3 is the most common investigated system, the notable charge trapping effects occurring in this system are preventing its practical use in SiC devices [11]. Hence, nanolaminated (Al_2O_3/HfO_2) [12] or stacked AlN/Al_2O_3 [13] systems have been proposed to overcome the limitations of single layers high-k, producing under appropriate condition epitaxial interfaces with promising electrical results.

On the other hand, AlGaN/GaN heterostructures grown on Si substrates are attracting the largest interest in the WBG community, owing to the perspectives of a large scale integration in Si-fabs. For this purpose, however, "Au-free" contact processes must be developed, in order to avoid contaminations and guarantee the CMOS compatibility [14]. Ti/Al/Ti and Ta/Al/Ta Au-free Ohmic contacts show low specific contact resistance ρ_c at 600°C, favoured by the formation of a TiN interface layer with a lower barrier Φ_B [15]. A further reduction of the annealing temperature and metal/AlGaN barrier has been recently achieved by inserting a thin Carbon interlayer at the Ti/AlGaN interface [16]

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(Fig. 1c). On the other hand, also a novel WC metallization has been considered as “Au-free” Schottky contact in AlGaN/GaN heterostructures [17], in alternative to the standard Ni/Au contacts.
Finally, the development of normally-off HEMTs is one of the most crucial challenges in GaN technology [18]. While normally-off p-GaN HEMTs are already commercialized, they still suffer from threshold voltage instability effects that can be associated to the defects generation upon gate bias stress [19]. In this technology, a correct prediction of the device lifetime can be reached only by taking into account the correct transport mechanisms at the metal gate / p-GaN interfaces [20]. As alternative approach, recessed gate hybrid MISHEMTs are currently under investigation in the GaN community. However, the choice of an appropriate gate insulator is still a critical issue in GaN technology. Al_2O_3 –based layers grown by ALD have been recently indicated as valid solution, despite the optimal processes to deal with metal/Al_2O_3/GaN structure is still under evaluation.

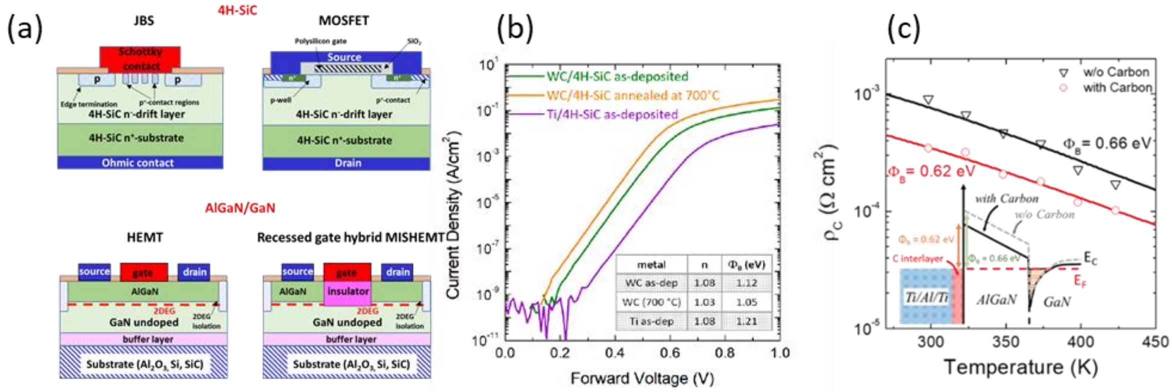

Fig. 1 (a): Examples of SiC and GaN devices. (b) Forward characteristics of 4H-SiC Schottky diodes with W and WC contacts, compared with the standard Ti metal. (c) Temperature-dependence of specific contact resistance ρ_c for Ti/Al/Ti contacts to AlGaN/GaN heterostructures without and with carbon interfacial layer.

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