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GaN-based microwave power devices: A survey on the activities in Europe

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1. Introduction

GaN devices for microwave applications are offering a great manifold of advantages for novel communication and military systems as compared to competing microwave power device technologies. In Europe research and development towards GaN high power electronic devices is intensively conducted in most of the countries. Targeted applications are highly linear power amplifiers for base stations in mobile communications, radar and automotive applications. National and European funding is supporting these developments and leads to joint efforts within the countries of the European Community.

2. Technological activities

Due to the lack of suitable highly resistive GaN substrates GaN microwave devices are fabricated on substrates enabling epitaxial growth of the device structures. Currently GaN devices are mostly grown on semi-insulating SiC substrates, sapphire and silicon. Some experiments on bulk GaN devices have also been reported. However the main stream of technological developments is currently focused to GaN epitaxial layers on SiC substrates mostly due to the relatively low lattice mismatch of 6H-SiC to GaN and because of the high thermal conductivity. This facilitates efficient heat removal especially for very high power devices. On the other hand many applications are heading to cost efficient technologies. In this respect the growth of GaN on Si associated with the corresponding device technologies is increasingly gaining interest in research and development. Triggered by requirements from optoelectronic devices significant activities are also going on with respect to free standing GaN and AlN substrates in order to reduce dislocation density and thus provide a material basis facilitating highly reliably devices.

Substrates and epitaxy

Research on SiC substrates has been intensified in the last years leading to commercially available SiC-substrates on the European market. Major players in this field are the companies Okmetic (Sweden), Umicore (Belgium), Si-Crystal (Germany) and NovaSiC (France). They are offering n- and p-type and partly (Okmetic) also semi-insulating SiC material. The current wafer size is 2”; larger substrates are under development. The respective crystal growth technologies differ from each other. Besides the abovementioned commercial vendors several research institutions are working on novel growth strategies that should have the potential to further improved material quality.

GaN bulk crystals showing extremely low defect densities of less than $1x10^2/cm^2$ are offered from Unipress (Poland). These type of crystals are used mainly for reference purposes in order to demonstrate device performance on practically dislocation free material.

Considerable progress related to the epitaxial lateral overgrowth method has been reported from various institutions (University of Ulm, Germany; CRHEA-CNRS, Sophia Antipolis, France; Ferdinand-Braun-Institut für Höchstfrequenztechnik (FBH), Germany; University of Lausanne, Switzerland). Commercially available GaN substrates are offered from the French company Lumilog. A special lateral overgrowth techniques on sapphire substrates allows the final removal of the as grown GaN wafer from the substrates thus producing free standing wafers.

Research on epitaxial layers for GaN/AlGaN HFETs is performed in a couple of companies, research institutes and universities. Optimized epitaxial growth on different substrates such as Sapphire, SiC, Si and others led to impressive device performances as discussed later. Table 1 gives an overview on the material growth activities towards GaN microwave power devices of various European institutions.

Table 1: Research activities on epitaxial growth techniques for electronic GaN-based devices in Europe

Institution	Country	Growth technique	Substrates	Remarks
CRHEA	F	MBE, MOVPE	Si, Al_2O_3, SiC	Specialized to GaN on Si growth techniques
Fhg-IAF	D	MOVPE	Al_2O_3, SiC	Growth and processing, multiwafer facility
IMEC	B	MOVPE	Al_2O_3, SiC	
Picogiga	F	MBE	Si, Al_2O_3, SiC	Commercial vendor
Qinetiq	UK	MOVPE	Al_2O_3, SiC	Growth and processing
TIGER	F	MOVPE	Al_2O_3, SiC	Growth and processing
Uni Aachen	D	MOVPE	Si	Growth and processing
Uni Lecce	I	MOVPE	Al_2O_3, SiC	
Uni Madrid	SP	MBE, MOVPE	Al_2O_3, SiC	Growth and processing, wafers<2”
Uni Magdeburg	D	MOVPE	Si	
Uni Sheffield	UK	MOVPE	Al_2O_3, SiC	
Uni Stuttgart	D	MOVPE	Al_2O_3, SiC	wafers <2”
Uni Ulm	D	MOVPE	Al_2O_3, SiC	Growth and processing

Device Processing

Device processing in order to verify epitaxial layer developments and to fabricate microwave devices for various system applications is performed at research institutes, companies and universities. In recent years intensive activities have been focused towards the establishment of reproducible wafer scale processes that are based on modern production oriented clean room facilities and equipment. Table 2 provides an overview on these facilities and typical processing techniques that are applied.

The major goals of all available device technologies is the reduction of the current slump phenomena by iterative epitaxial layer and processing optimization. Additionally increased attention is paid to thermal management of high power devices. For this purpose backend processed devices on sapphire and SiC are currently developed at the IAF, Freiburg, Germany, at the FBH, Germany and at Tiger in France. The backend processes including via technology will facilitate conventional power cell design and chip mounting techniques. On the other hand also flip chip techniques are considered for thermally optimized device mounting techniques.

Table 2 summarizes the major European processing capabilities for GaN based microwave power devices. An overview is also given in [1]. In Figure 1 the results obtained from on wafer measurements of GaN microwave devices on SiC substrates are given. Power levels of 14 W at 2 GHz (FBH, [2]), 8 W at 10 GHz (DC) and 0.9 W at 40 GHz (FhG-IAF, [3]) have been obtained. The results obtained on sapphire and Si-substrates are individually identified. Remarkable power densities of 6.6 W/mm have been demonstrated by DaimlerChrysler on Si-substrates grown by CRHEA [4].

Table 2: Full wafer scale industry relevant processing of electronic GaN-based devices in Europe

Institution	Country	General technology	Ohmics	Gate technology		Inter-connects	Passivation	MMICs
				Material	length			
AleniaMarconi	I	2” to 4”					SiN_x, PECVD	no
DaimlerChrysler (DC)	D	2“ to 4“	Ti/Al/Ni/Au	Pt/Au	>0.25 µm	2	SiN_x, PECVD	yes
FBH	D	2“ to 4“; stepper lithography	Ti/Al/Ti/Au/W SiN	Pt/Au	>0.25 µm	2	SiN_x, PECVD	no
FhG-IAF	D	2” to 4”	Ti/Al/Au	Ni/Au	>0.15 µm	2	SiN_x, Sputter	yes
Qinetiq	UK	2”	Ti/Ni/Ti/Au	Ni/Au	>0.25 µm	2	SiN_x	yes
TIGER	F	2” to 4”	Ti/NiTi/Au	Pt/Au	>0.15 µm	2	SiO /SiN , ICP	no

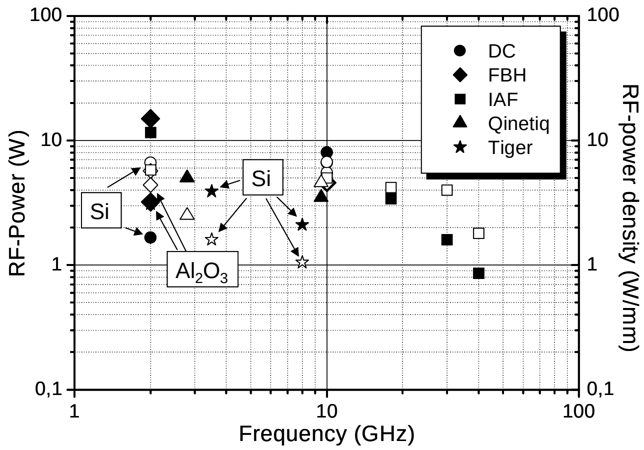

Figure 1: Results from GaN based microwave power devices as fabricated at various European institutions. The measurements have been taken on-wafer, substrate material is SiC unless denoted explicitly. The closed and the open symbols represent the total rf-power (W) and the power density (W/mm) respectively.

3. Conclusions

GaN activities towards microwave power applications have been substantially enforced in Europe during the last years leading to impressive results. It can be foreseen that the ongoing tests of prototype GaN devices in system applications will provide a clear chance for industrial exploitation of GaN microwave devices in the near future.

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References

[1] S. Delage, H. Zirath, *Wide bandgap semiconductors, workshop organized at the European Microwave Week 2002, Milan, Proceedings.*

[2] R. Lossy, N. Chaturvedi, P. Heymann, K. Köhler, S. Müller and J. Würfl, *AlGaN/GaN HEMTs on Silicon Carbide Substrates for Microwave Power Operation,* Digest of GaAs MANTECH 2003 p.327, published by GaAs MANTECH Inc., St.Louis.

[3] R. Kiefer, R. Quay, S. Müller, T. Feltgen, B. Raynor, J. Schleife, K. Köhler, H. Massler, S. Ramberger, F. van Raay, A. Tessmann, M. Mikulla, G. Weimann, *Development of a 2“-AlGaN/GaN HEMT Technology on Sapphire and SiC for mm-Wave High-Voltage Power Applications, phys. stat. sol (2003).*

[4] R. Behtash, H. Tobler, P. Marshall, A. Schurr, H. Leier, Y. cordier, F. Semond, F. Natali, J. Massies, *AlGaN/GaN HEMTs on Si (111) with 6.6 W/mm output power density, Electr. Lett. 39, 626 (2003).*