Process Benchmarking of SiC Backside Via Manufacturing for GaN HEMT Technology

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ABSTRACT

GaN technology is rapidly becoming of increased importance for many IC manufacturers. Backside processes are especially often challenging for GaN technologies due to the types of substrate material used. In comparison to GaAs and Si technologies, less know-how exists for the integration of a via hole process in thinned SiC substrates with an active GaN EPI layer in a manufacturing area. In this work we present benchmarking of a SiC via hole process for GaN HEMT technology in terms of quality, integration and production points of view, tool investment and maintenance. Two process flows will be described and compared to each other. One flow utilizes a state of the art process with an ICP etch of the SiC using a hard mask and the other a blind hole process using a laser source with optimized parameters for a high SiC ablation rate. The major difference between these processes is that the ICP process etches via holes simultaneously and the laser ablate the vias sequentially.

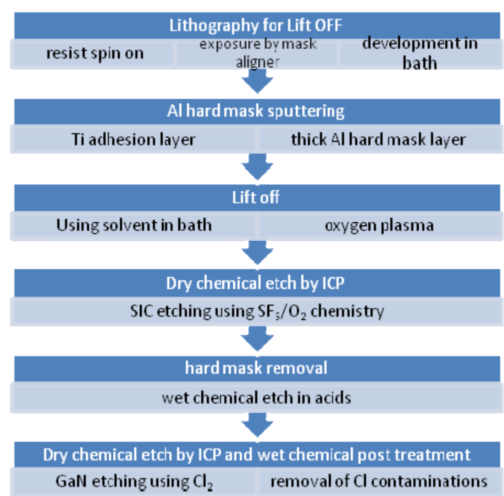
INTRODUCTION

The competitive nature of laser ablation compared to dry chemical etching for the generation of via holes is explained by the high binding energy of SiC. The ion energy of the plasma process has to be very high in order to crack the Si – C bonds. That means the process has to be mainly physical assisted. This high ion energy leads to high temperature dissipation during the via hole process which lead to difficulties in process integration of the wafer bonding process. Furthermore wafer temperatures can reach 250-300°C for several hours during etching and it is not clear what impact it can have on the GaN device itself. In this respect, laser processing demonstrates a clear benefit, since the laser is evaporating the material. The locally heated structures by the laser ablation area can easily conduct the temperature to the SiC substrate that builds up a big heat sink.

ICP ETCHING IN SIC

As mentioned above, the etching of vias can take several hours in the case of a 100 µm thick SiC substrate. Furthermore, since the utilized mask has to withstand high temperatures, ion energy and oxygen content of the plasma, a hard mask is necessary. For the etching of SiC, fluorine chemistry is used and dielectrics such as silicon oxides or nitrides cannot be used owing to their poor selectivity to SiC. This means a metal or a metal compound hard mask has to be used.

Several semiconductor processes are necessary in order to generate low resistivity through interconnects from the wafer backside to the front side source contacts of the devices. These processes will lead to capacity reduction of available tools used for lithography, metallization, wet and dry chemical etching. The etch rate of the SiC in an ICP etching tool is about 0.6 µm per minute which lead to process times of several hours for the processing of SiC/GaN EPI wafers thinned down to 100µm. The costs of investment and operation are quite high for an ICP tool compared to the low wafer throughput. The following process flow chart shows the single steps that are necessary for the via hole level of a GaN Hemt backside process.



The quality of the realized via holes depends strongly on the wafer surface roughness, mask slope and the etch selectivity of the SiC to the mask material. Figure 1 shows a cross section view of a via hole etched by ICP. The side wall roughness is strongly influenced by the mask edge roughness as well as the slope of the mask edge. In order to get a smoother and perpendicular sidewall it is required to attain a very high selectivity of SiC to the mask material. As the physical component of the plasma process has to be very high it is very difficult to reach high selectivity using state of the art ICP etching tools.

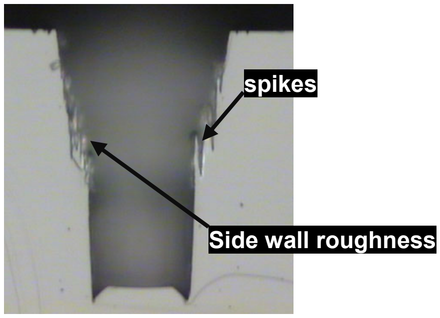


Figure 1: via profile etched in SiC using an ICP etching process

Beside the side wall roughness, micro masking effects can take place that lead to grass-type defects within the via holes. These defects depend strongly on the wafer surface roughness produced by any prior SiC thinning processes. It is necessary to attain a wafer surface roughness of about 3 nm of mean roughness (R_a) , without any large defects or scratches. In the case of an aluminum hard mask, the build up of aluminum fluorides and the associated reduction in surface quality can also lead to grass-type defects. Additionally, aluminum fluorides can passivate the side wall of the via hole during plasma etching, and this sidewall passivation has to be removed by acids and plasma chemical post treatments at a later stage during processing. The wafer surface temperature can also reach 250°C during SiC etch for periods of several hours, and any high temperature bonding material utilized to attach the wafer to a carrier has to withstand this. Temporary wafer bonding adhesives consist of organic materials that withstand temperatures of about 150°C. Today thermoplastic materials are stable up to 250°C for temporary wafer bonding. These materials are weakened at about this temperature and the wafer can be sliced off if the adhesive is not destroyed by the high temperature budget during the SiC dry chemical etch. Rough sidewalls and grass defects cause several problems for any subsequent metallization steps. Such problems cause any utilized seed layer for the electroplating process to crack, leading to nonconformal electroplating of metal layers inside the via.

The spikes at the side wall (figure 1 and 3) accelerate the growth of electroplated material. This leads to a depletion of metal at the bottom region of the via hole. Furthermore, the risk of voids in the metal layers is quite high. The process integration of the whole backside process has to be considered carefully in terms of via hole quality.

LASER DRILLING IN SIC

Former studies of different working groups showed the ability of SiC laser ablation [A] [B] [C]. Additionally comparisons of via hole quality with respect to side wall roughness and residues are made using an ICP or laser ablation process. In this work we focus on the quality of the via hole profile, side wall and bottom roughness using an excimer laser at 193 and 248 nm wavelength

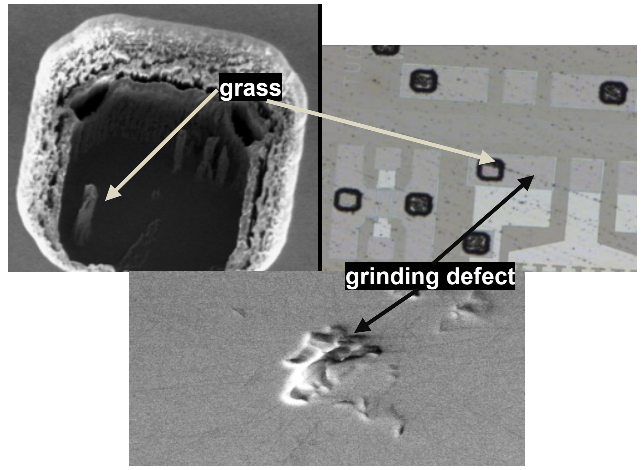


Figure 2: Grass formation due to grinding defects and scratches

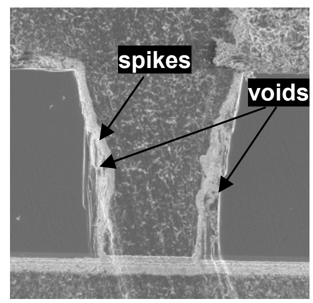


Figure 3: cross section view of metalized via hole in SiC/GaN EPI wafer.

In case of the laser ablation, there is no need for a lithography mask as the via holes can be transferred from the GDS file to the system and will be printed on the wafer. The complexity of process integration and processing time can be greatly reduced using an adequate laser source for the SiC ablation. Figure 4 shows the process flow that begins with the deposition of a thin metal layer which serves as mask for the silicon carbide etch through and protection against debris coming from the laser ablation. Laser ablation has a very low selectivity to the GaN by comparison to the ICP etching process. That means there is no natural etch stop possible when using a laser. Therefore, the laser has to stop in the SiC bulk material accurately at a pre-defined depth with a very smooth via bottom. The depth of the blind holes has to be controlled very accurately in order to stop about 5 µm in the SIC before reaching the GaN layer.

After laser ablation the debris layer are removed by a wet chemical clean. The remaining SiC to the GaN is etched by an ICP plasma process using a high selective etching process to the GaN. Finally the GaN and the thin aluminum metal layer will be etched in situ in the same dry etch tool using chlorine chemistry.

In this work we utilized solid sate and excimer laser sources for the blind via hole drilling. The solid state laser emits a point beam profile with a Gaussian intensity distribution. In order to achieve a via hole of 50 µm in

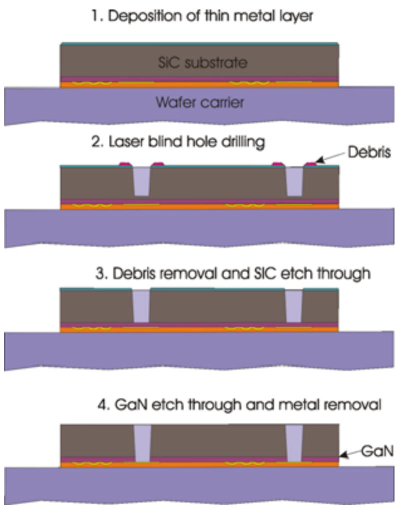


Figure 4: process flow of laser blind hole drilling

diameter, a trepanning movement of the beam is necessary to drill the blind hole. The blind holes show a pattern of the laser beam movement at the blind hole bottom when the drilling stops. Figure 5 shows the top view of a blind hole bottom with a helical shape (left hand). There remains a deep hole of about 5 µm of the last shot of the laser beam (right hand). As a flat via bottom is necessary a point profile of the solid state laser source of the beam is not applicable. In order to overcome that problem the Gaussian beam profile has to be transferred to a top hat profile with a rectangular intensity distribution. At this point the solid state laser tests stopped and the focus were now on excimer laser sources.

The excimer laser emits the light in an area of a uniform intensity profile. The area of the uniform intensity profile is several mm in square depending on the laser source and optics used. The diameter of the hole is defined by a mask which is introduced in the optics of the laser beam.

In this work we undertook trials with an excimer laser wavelength of 193 nm and 248 nm. Both wavelengths show a good quality of the via hole bottom flatness and smooth side walls (figure 6).

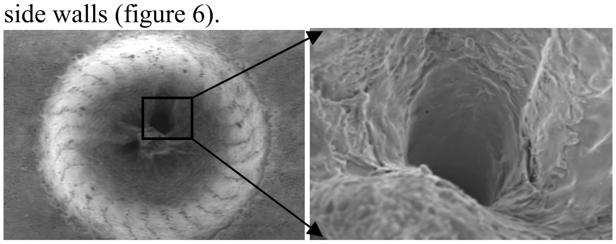


Figure 5: Blind hole bottom with a solid state laser source (wavelength of 532nm)

Laser ablation produces debris at the edges of the hole entrance. EDX analysis of the debris show strong peaks of silicon and oxygen that indicates the presence of silicon oxide. The profile of the via holes are perpendicular shaped with a slight trenching at the edges of the via bottom (Figure 7).

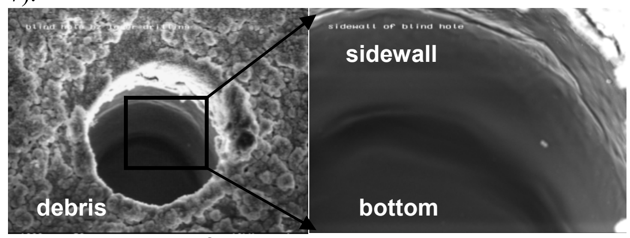


Figure 6: top view of an blind hole drilled by an excimer laser (248 nm)

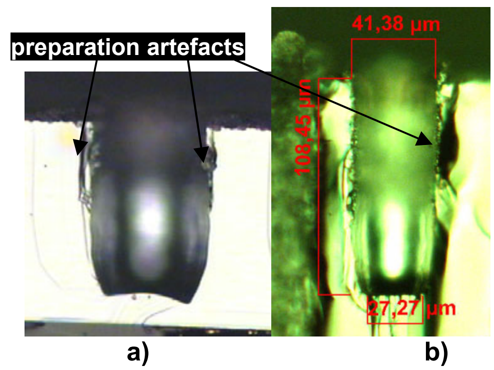


Figure 7: cross section view of blind hole drilled by an excimer laser (a) 193 nm, (b)248 nm (source: FBH Berlin)

The laser ablation rate of SIC depends mainly on the pulse energy and the repetition rate of the laser source used.

Figure 8 shows the SiC ablation rate as a linear function of the repetition rate. The number of shots defines the blind hole depth. The ablation rate decreases with increasing depth of the drilled blind holes especially at higher laser repetition rate. This effect can maybe overcome by reducing the laser pulse time in order to avoid ablated material interactions from pulse to pulse. The via hole bottom and profile quality is not influenced by the increase of repetition rate.

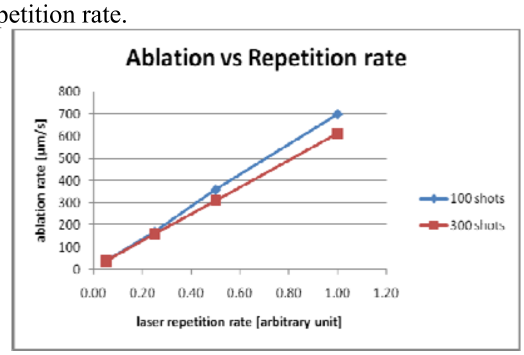


Figure 8: Excimer laser ablation rate vs repetition rate (source: Coherent GmbH Göttingen)

Based on the achieved ablation rate it is easy to calculate the processing time as a function of number of blind holes. If we include the wafer table movement, the via hole alignment of the laser system and the ICP etch through of the silicon carbide and gallium nitride we calculate a raw processing time for 10000 holes of 96 min and for 40000 holes of 294 min. This process flow was tested and there were achieved a through wafer via contact resistance to the front side source contact of 11 mohms.

BENCHMARKING OF PLASMA ETCH VS LASER ABLATION TOOL

The achieved results show the process ability of both concepts. Two different process flows and main features of the via hole process modules are described. In this Section the benchmarking of the ICP plasma etch tool and the laser system will be done in terms of IC manufacturing. The costs of invest of a laser system is about half the price compared to an ICP etching tool. This difference of price is caused by the additional technical systems and high purity materials for the etch chamber. Costs of maintenance and operation for an excimer laser system can be quite well predicted and the consumables are less compared to a plasma etching tool. The excimer gas consumption and the laser tube abrasion of the excimer laser depends on the number of shots and pulse energy used. The investment costs for the beam forming optics depend strongly on the power and wavelength that is used for the excimer laser source. The higher the power and the lower the wavelength, the higher the maintenance costs for the laser source and beam forming optics could be, if a non-adequate system concept and design is used. Excimer laser tubes and optics generally show a shorter lifetime with the wavelength of 193 nm. This can be explained by the higher photon energy at this wavelength. The infrastructure of a plasma tool like the vacuum systems, gas cabinets and reactive gas post treatment systems increases the cost of installation, operation and consumables dramatically.

From a technical point of view, the process integration of the whole backside process module is less complex using a laser blind hole process. The quality of the blind holes are better if the via hole profile and the side wall roughness at taken into account. Additionally the low chemical selectivity of the laser compared to the dry chemical etching helps to increase process stability. The process time of the laser drilling depends on the amount of vias. This aspect can reduce or raise the processing time. Therefore the laser system has to be optimized to a high SiC ablation rate, fast table movement and alignment system in order to be competitive to the ICP etching tool. Process Development is less time consuming for the laser ablation compared to the ICP plasma process as there are less variable process parameters for the laser tool. This leads to a higher ROI for the laser system.

Finally, Figure 9 shows a rating between both concepts from 1 (bad) to 5 (good). The rating shows that the laser concept with 29 points will beat the ICP etching process with 18 points.

CONCLUSIONS

The work shows that in terms of process complexity

comparison of concepts	ICP etching		Laser ablation	
Investment	ICP tool	1	laser tool	3
Maintenance	ICP tool+ infrastructure	2	Laser tool + infrastructure	3
Technical point of view	high temperature evolution during etching	2	no risk of delamination of bonded wafer	5
	Selective etch stop of vias	5	complex blind hole processing concerning etch throughs	4
	metall hard mask process necessary	2	no hard mask process necessary	4
Production point of view	RPZ 385min	2	RPZ 96 - 294min	4
	process stability	2	process stability	3
	reproducibility	2	reproducibility	3
Total		18		29

Figure 9: Rating of laser vs dry chemical etching concept

and technical challenge, the laser ablation process would be a good alternative compared to the state of the art processing technologies of semiconductor industry. If we take other aspects into account like production infrastructure laser systems are more and more used in the low volume markets of MEMS and IC manufacturers. The investment, maintenance costs are much lower compared to plasma etching equipments. The pros and cons have been shown for backside process concepts of GaN technology on SiC substrates.

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