High Temperature Electrical Electronics Equipment: - Broad Bandgap Semiconductor

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Abstract: - *Now a days power electronic devices have reached fundamental restrictions imposed by the low breakdown field, low thermal conductivity and limited switching frequency of Si. Substantial perfections can only be achieved by turning over to semiconductors showing extraordinary performance in the frame. These are WBG semiconductors which found GaN, SiC and Diamond which have long been swashed for their potential superior presentation in high frequency and high power applications. This review paper envisages the core aspects of WBG semiconductors, appraisal on the basis of their characteristics and their applicability in power electronics. It also comprises an overview of the market for WBG semiconductors and the future perspective for power devices*

Key Words: Power electronics, High Temperature, Wide Bandgap Semiconductor, Diamond, Gallium Nitride, Silicon Carbide.

1. INTRODUCTION

Power Electronics play a key role in the generation-storage circulation cycle of the electric energy. This is since the main portion of the produce electric energy is expended after undergoing quite a lot of alterations, several of them carried out by power electronic converters. The major portion of the power losses in these power electronic converters are dissolute in their power semiconductor devices. At present, these devices are recognized on the complete and well established Silicon technology. However, Si exhibits some important limitations regarding its blocking capability, operation temperature and switching frequency. Therefore, a new generation of power devices is required for power converters in applications in which electronic systems based on regular Si power devices cannot operate.

The base materials for these new power devices, SiC and GaN present the better trade-off among hypothetical physiognomies and real commercial availability of the starting material (wafers) and maturity of their technological processes. Most present commercial power electronic devices (diodes, thyristors, IGBTs, MOSFETs, etc.) are silicon based. The performance of these systems is approaching the theoretical limits of the Si fundamental material possessions.

The appearance of new power electronic devices grounded on wide Bandgap (WBG) semiconductor materials will likely result in substantial improvements in the performance of power electronics converter systems in terms of sophisticated blocking voltages, efficiency, and trustworthiness as well as reduced thermal necessities.

2. PROPERTIES OF WIDE BANDGAP SEMICONDUCTORS

Wide Bandgap semiconductor materials have superior electrical characteristics compared with Si. Some of these characteristics are tabulated for the most popular wide band gap semiconductors and Si in Table I. Among all these semiconductors, diamond has the widest Bandgap; consequently, it also has the highest electric breakdown field. SiC poly types and GaN have similar Bandgap and electric field values which are significantly higher than Si and GaAs. Semiconductors with wider Band gaps can operate at higher temperatures; therefore, diamond power devices have the capability to operate at higher ambient temperature than the other materials. In addition, a higher electric breakdown field results in power devices with higher breakdown voltages. For example, the breakdown voltage of a diode is expressed in [1] as follows:

$$V_B \approx \frac{\varepsilon_r E_c^2}{2qN_d} \quad (1)$$

Where q is the charge of an electron and Nd is the doping densityUsing(1), the break down voltages of diodes made of the materials in Table-I are calculated as summing the same doping density, and the results are plotted inFig.1 with the break down voltages normalized to that of a Si diode. As seen in this figure, the hypothetical break down voltage of a precious stone diodes 514 times more than that of a Si diode. This number for 6H-SiC, 4H-SiC, and GaN is 56, 46, and 34 times that of a Si diode, individually. Note that with a better electric break down field, more doping can be applied to the fabric which is able encourage increment the crevice between the upper break down voltage limits of the wide band hole semiconductors compared to Si.another result of the higher electric break down field and higher doping density is the width decrease within the float locale of the gadgets. The desired width of the float locale can be communicated as [2]

$$W(V_B) \approx \frac{2V_B}{E_c} \quad (2)$$

Property	Si	GaAs	6H-SiC	4H-SiC	GaN	Diamond
Bandgap, Eg (eV)	1.12	1.43	3.03	3.26	3.45	5.45
Dielectric constant	11.9	13.1	9.66	10.1	9	5.5
Electric Breakdown field ,Ec (kV/cm)	300	400	2500	2200	2000	10000
Hole Mobility μ_p(cm^2/V-s) 600	600	400	101	115	850	850
Electrone Mobility μ_n (cm^2/V-s)	1500	1850	50080	1000	1250	2200
Thermal Conductivity , (W/cm K)	1.5	4.6	4.9	4.9	1.3	22
Saturated Electron Drift Velocity, vsat (10^7 cm/s)	1	1	2	2	2.2	2.7

Table 1: Physical characteristics of Si and main wide band gap semiconductors

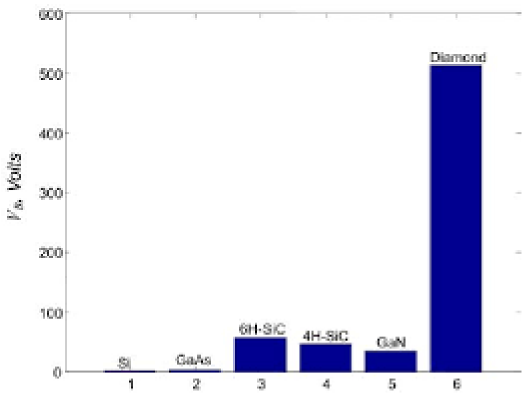

Fig 1. Maximum Breakdown Voltage of a power device at the same doping density normalized to Si

The width of the float locale is calculated for all the semiconductors in Table I, and the comes about are plotted in Fig. 2 for a breakdown voltage extend of 100 to 10,000 V. Jewel, as anticipated, requires the least width, whereas 6H-SiC, 4H-SiC, GaN take after precious stone within the arrange of expanding widths. Compared to these, Si requires roughly a 10 times thicker float locale .The final gadget parameter to be calculated from the properties in Table I is the on-resistance of the float locale for unipolar gadgets, which is given by the condition underneath [3]

$$R_{on,sp} = \frac{4\left(V_B^2\right)}{\varepsilon_s (E_c)^3 \mu_n} \quad (3)$$

The calculation comes about for on-resistance are plotted in Fig. 3 with regard to the breakdown voltage of the gadget. Once more, jewel appears the most excellent execution with 4H-SiC, GaN, and 6H-SiC taking after in expanding resistance arrange. The on-resistance of the float locale for the Si gadget is around 10 times more than the SiC poly sorts and GaN gadgets. Note that contact resistance and/or channel resistance must too be considered when the gadget on resistance is calculated. These two resistances are prevailing at moo breakdown voltages but can be neglected at high breakdown voltages; subsequently (3) may be a superior guess of the gadget on-resistance for higher breakdown voltage gadgets.

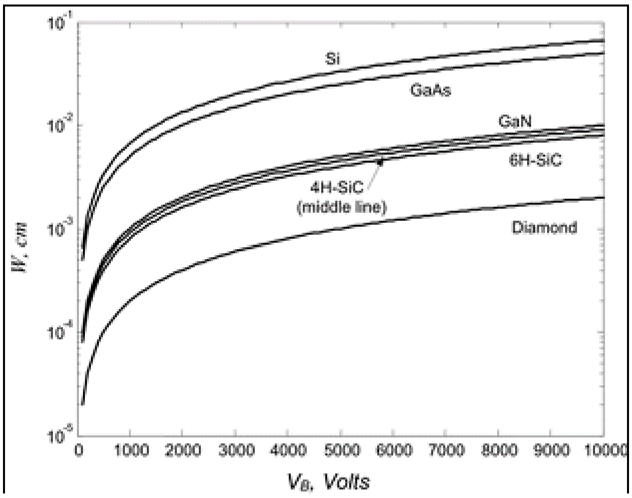

Fig. 2: Width of the drift region for each material at different breakdown voltages.

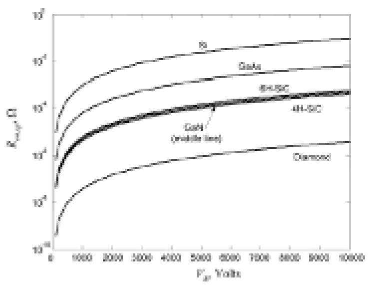

Fig. 3: Resistance of the drift region for each material at different breakdown voltages.

Another parameter to highlight in Table I is the warm conductivity. The more noteworthy this parameteris,the waybetter the fabric conducts warm toits environment, whichimplies the gadget temperature increments more slowly. For higher temperature operation, usually a basic property of the fabric. Precious stone still leads the other materials byat slightest a figure of five, with the SiC poly-types as the following best materials. GaN has the most exceedingly bad warm conductivity - indeed lower than Si. For distant better much better higher; a stronger; an improved">an improved comparison of the conceivable control gadgets exhibitions of these materials, a few commonly known figures of justify are recorded in Table II. In this table, the numbers have been normalized with regard to Si; a bigger number speaks to a material's better performance within the comparing category. The figure of justify values for precious stone are at slightest 40-50 times more than any other semiconductor within the table. SiC poly types and GaN have comparative figuresof justify,

	Si	GaAs	6H-SiC	4H-SiC	GaN	Diamond
JFM	1.0	1.8	277.8	215.1	215.1	81000
BFM	1.0	14.8	125.3	223.1	186.7	25106
FSFM	1.0	11.4	30.5	61.2	65.0	3595
BSFM	1.0	1.6	13.1	12.9	52.5	2402
FPFM	1.0	3.6	48.3	56.0	30.4	1476
FTFM	1.0	40.7	1470.5	3424.8	1973.6	5304459
BPFM	1.0	0.9	57.3	35.4	10.7	594
BTFM	1.0	1.4	748.9	458.1	560.5	1426711

BFM : Baliga's figure of merit is a measure of the

Specific on-resistance of the drift region of a vertical FET

 FSFM : FET switching speed figure of merit

 BSF :Bipolar switching speed figure of merit

 FPFM : FET power handling capacity figure of merit

 FTFM : FET power switching product

 BPFM : Bipolar power handling capacity figure of merit

 BTFM : Bipolar power switching product

Presently, two SiC poly types are popular in SiC research: 6H-SiC and 4H-SiC. Before the introduction of 4HSiC wafers in 1994, 6H-SiC was the dominant poly type. Since then, both of these polytopes are used in research, but recently 4H-SiC has become the more dominant poly type. Although both of these polytopes have similar properties, 4HSiC is preferred over 6H-SiC because of the latter's anisotropy, which means the mobility's of the material in the vertical and horizontal planes are not the same whereas the mobility's in 4H-SiC are identical along the two planes of the semiconductor.

IV. GALLIUM NITRIDE

Applications of GaN devices are mainly focused on

Optoelectronics and radio frequency uses because of its direct bandgap and high frequency performance, respectively. As seen in Section II, however, GaN also has a potential for high power electronics applications. In the last few years, some papers have been published in the literature on high voltage GaN Schottky diodes [9-13]. The comparison of GaN Schottky diodes with SiC Schottky and Si pn diodes at similar blocking voltages show a performance advantage of the GaN Schottky diode similar to SiC compared to the Si pn diode, mainly negligible reverse recovery current and consequently lower switching loss that is independent of the operating temperature. The switching speed and losses of GaN Schottky diodes have been shown to be slightly better than similarly rated SiC diodes [9]. On the other hand, because of its wider bandgap, GaN Schottky diode's forward voltage drop is much higher than both Si pn and SiC Schottky diodes.In the literature, up to 2 kV GaN Schottky diodes and up to 6 kV [11] GaN pn diodes have already been demonstrated; however, 4.9 kV SiC Schottky diodes and 19.2 kV pn diodes have also been demonstrated. These figures show how advanced SiC technology is at this point compared to GaN technologyGaN has some disadvantages compared to SiC. The first one is that it does not have a native oxide, which is required for MOS devices. SiC uses the same oxide as Si, SiO2. For GaN, more studies are underway to find a suitable

Oxide; without it, GaN MOS devices are not possible. The second important problem is that with the present technology, GaN boules are difficult to grow. Therefore, pure GaN wafers are not available (see section 6 for more information); instead GaN wafers are grown on sapphire or SiC .Even then, thick GaN substrates are not commercially available. As a consequence, GaN wafers are more expensive than SiC wafers.An additional disadvantage of GaN compared to SiC is its thermal conductivity, which is almost one- fourth of that of SiC. This property is especially important in high power, high temperature operation because the heat generated inside the device needs to be dissipated as quickly as possible. The higher the thermal conductivity is, the quicker the heat is dissipated. Growing GaN on SiC wafers increases the overall thermal conductivity but still does not reach the performance of SiC.

V. DIAMOND

Diamond shows the best theoretical performance as shown in Section II, with several times improvement in every category compared with every other wide bandgap semiconductor. However, its processing problems have not been solved yet. After several years of research, SiC still has processing issues because of the high temperatures required in the process; diamond is a harder material and needs even higher temperatures for processing, and not as much research has been done on its processing yet.

VI. COMMERCIAL AVAILABILITY OF WAFERS

Si and GaAs semiconductors wafers are available in

Diameters of up to 15 cm and variable thickness from 225 to 675 µm. Because of their abundance, they are cheap with a price of less than $100 U.S. each. GaN and SiC wafers are not abundant; therefore, they are expensive, in the $2000 – $3000 U.S. range. Even

Though the prices of SiC and GaN wafers are expensive; with mass production, the prices will likely decrease to close to Si and GaAs wafer price levels. SiC wafers are available up to 7.5 cm with a thickness of 254-368 µm. The best SiC wafers have less than one micropipe per square-cm; however, the most common wafers have less than ten micropipes per square-cm with less

Than five micropipes per square-cm around the center of the wafer. GaN wafers generally come in two forms: GaN on SiC or GaN on sapphire. The former is suitable for power device applications and the latter for LEDs and other optical applications. Recently, a company claimed to have produced the first true bulk GaN, but no commercial products are available yet. The diameter and the thickness of the commercially available wafers are rather small at 5 cm in diameter and up to 25 µ m thickness.

VII. COMMERCIALLY AVAILABLE WBG SEMICONDUCTORBASED POWER DEVICES

As of April 2003, only GaAs and SiC Schottky diodes are available for low power applications. SiC Schottky diodes are available from four.

VIII. FORECASTING THE FUTURE

With further development, wide bandgap semiconductors have the opportunity to meet demanding power converter requirements. While diamond has the best electrical properties, research on applying it for high power applications is only in its preliminary stages. Its processing problems are more difficult to solve than any of the other materials; however, it likely will be an important material for power devices in 20 to 50 years. In the meantime, transitional material will likely replace Si for many high power

applications. GaN and SiC power devices show similar advantages over Si power devices. GaN's intrinsic properties are slightly better than SiC; however, no pure GaN wafers are available, and thus GaN needs to be grown on SiC wafers.SiC power device technology is much more advanced than GaN technology and is leading in research and commercialization efforts. The slight improvement GaN provides over SiC might not be sufficient to change gears and use GaN instead of SiC. SiC is the best suitable transition material for future power devices.

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