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Development of α-Ga_2O_3 Power Devices by MIST EPITAXY®

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Abstract

Corundum-structured Ga_2O_3 (α-Ga_2O_3) is a new candidate for next-generation power device materials due to its excellent physical properties. Thin film SBDs with extremely low specific on-resistance of 0.1 mΩ·cm² (breakdown voltage 531 V) were successfully demonstrated using MIST EPITAXY® technology. 600 V class SBDs packaged in TO-220 have been developed and is nearing practical use. In addition, the world's first normally-off α-Ga_2O_3 MOSFET was demonstrated.

1. Introduction

For several decades the power electronics industry has relied on Si semiconductor devices. However, the physical limitations of Si have triggered the development of wide bandgap semiconductors, including SiC (E_g = 3.3 eV) and GaN (E_g = 3.4 eV). On the other hand, it is reported that corundum-structured Ga_2O_3 (α-Ga_2O_3) (E_g = 5.3 eV), which is one of the metastable phases in Ga_2O_3 polymorphs, thin films can be obtained by mist chemical vapor deposition (mist-CVD) [1]. Using inexpensive sapphire substrates and mist CVD growth technique, there is a possibility to fabricate Ga_2O_3 devices at low cost.

2. Distinct Features of Gallium Oxide

Gallium oxide takes five different phases (α, β, γ, δ, and ε). The orthorhombic β-gallia structure (β-phase) is the most stable crystal structure [2], and corundum-structure (α-phase) has the widest bandgap among them. As shown in Table I and Figure 1, the breakdown electric field (E_c) of α-Ga_2O_3 is about 30 times that of Si and 4 times that of SiC, and that offers the following advantages of α-Ga_2O_3 power devices over counterparts: (1) the thickness of the drift layer of α-Ga_2O_3 can be reduced to 1/30 of that of Si and 1/4 of that of SiC, and also higher doping is possible to the drift layer of α-Ga_2O_3, those combined enable reduction of the drift layer resistance to 1/6,726 that of Si and 1/20 that of SiC in unipolar devices; and (2) the use of the same drift layer thickness enables a blocking voltage of 30 times that of Si and 4 times that of SiC. The characteristics (1) would enable further reduction of the on-resistance of unipolar devices. The characteristics (2) would enable the fabrication of devices operating at ultra-high blocking voltages (> 10 kV) and it would be possible to reduce the number of series connected devices required for construction of high power converter systems. Further, the wide bandgap of α-Ga_2O_3 (E_g = 5.3 eV) enables high temperature operation.

3. α-Ga_2O_3 Power Devices

α-Ga_2O_3 films were grown on a sapphire substrate by MIST EPITAXY® technology [3], which was originally developed in Kyoto University [1]. Solution of the Ga source materials were atomized, and the generated mist was carried with the carrier gas to a reaction furnace, and α-Ga_2O_3 film was grown on a sapphire substrate set in the furnace at the controlled temperature as shown in Fig. 2.

Two types of small vertical SBDs were fabricated to confirm the device performance. SBD1 was designed to show low on-resistance, and therefore the thickness of the n^- layer was set at 430 nm. SBD2 was designed to show higher breakdown voltage and had a thicker n^- layer of 2580 nm. The breakdown voltage was as high as 531 and 855 V for SBD1 and 2, respectively. The differential specific on-resistance was 0.1 and 0.4 mΩ·cm², respectively [3]. On the next stage, 600 V class large SBDs (> 1mm) were developed and packaged in TO-220. Thin (< 10 μm) α-Ga_2O_3 layer was attached on metal substrate to reduce thermal resistance. These SBDs have been applied to 1MHz boost converters and showed high efficiency.

The world's first α-Ga_2O_3 normally-off MOSFET was successfully demonstrated as shown in Fig. 3 [4]. The gate threshold voltage extrapolated from I-V curve was 7.9V. The device is made of a novel p-type corundum semiconductor which functions as an inversion layer. Development of vertical power MOSFET is ongoing.

4. Conclusions

The development of α-Ga_2O_3 power devices has proceeded rapidly in just 10 years after the α-Ga_2O_3 thin film was obtained by mist CVD growth technique in 2008, and soon the first device is about to be on the market. A great leap in the future of α-Ga_2O_3 power devices is expected.

Acknowledgements

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References

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Table I Comparison of physical properties with competing materials.

Name of material		Si	4H-SiC	GaN	β-Ga_2O_3	α-Ga_2O_3 (Corundum structure)
Bandgap Eg (eV)		1.1	3.3	3.4	4.5	5.3
Mobility μ (cm²/Vs)		1,400	1,000	1,200	300	300 (estimate)
Dielectric breakdown field Ec (MV/cm)		0.3	2.5	3.3	7	10 (estimate)
Relative dielectric constant		11.6	9.7	9.0	10	10 (estimate)
Baliga's figure of merit Si = 1	Low frequency ($\varepsilon\mu E_c^3$)	1	340	870	2,307	6,726 (estimate)
	High frequency (μE_c^2)	1	50	104	117	238 (estimate)

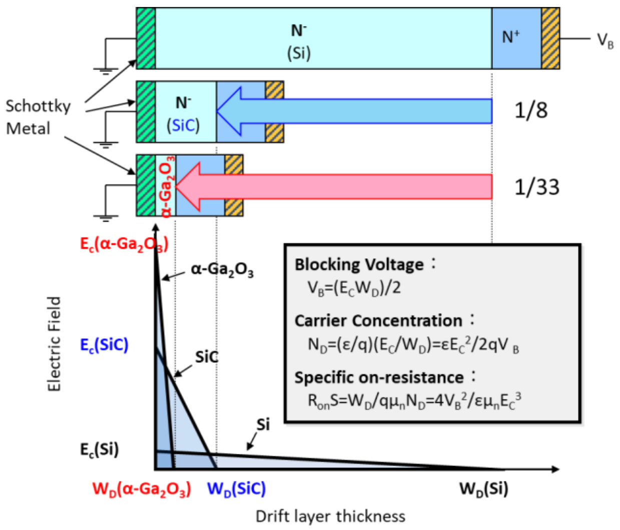
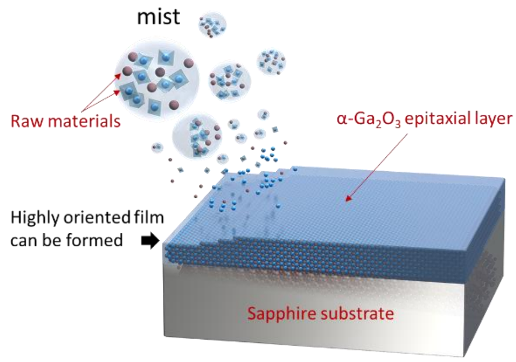


Fig. 1 The reason why low on-resistance can be attained.



1） Solution of raw materials are atomized, and the generated mist is carried with the carrier gas into a reaction furnace
2） Mist evaporates little by little by heating
3） Highly oriented film can be formed by chemical reaction

Fig. 2 MIST EPITAXY® method.

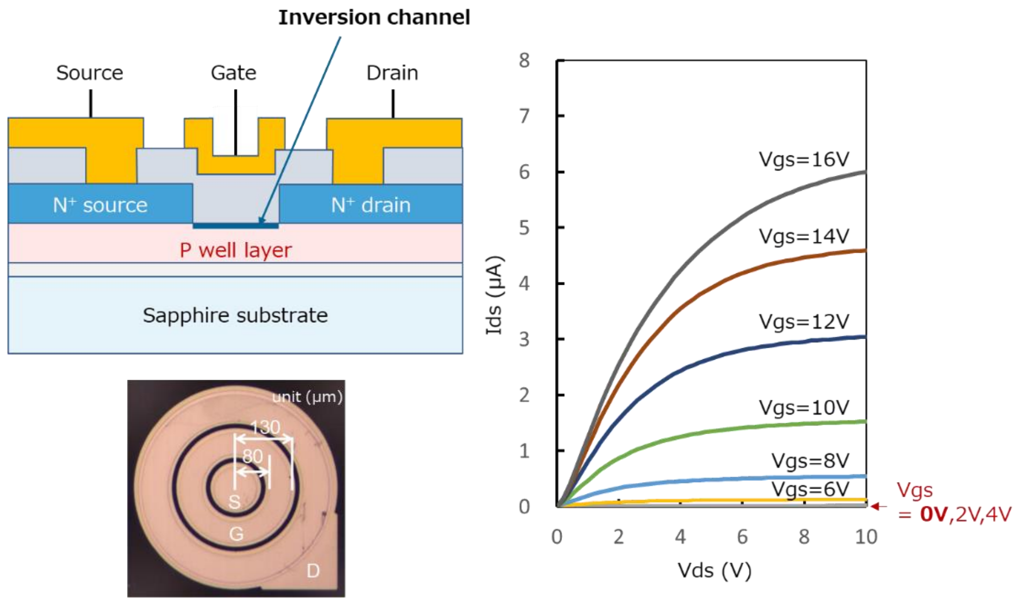


Fig. 3 Fabricated normally-off α-Ga_2O_3 MOSFET