High Voltage Silicon Carbide Power Device Technology

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1.2. Introduction

This report was commissioned to provide an overview of the silicon carbide (SiC) power device supply chain, as it relates to high and ultra-high voltage (HV and UHV) ratings. At each rung of the supply chain, one can find detailed subject reviews, reports and journal papers that delve deep into its subject. This report aims to condense the key elements of these detailed reports into a readable cohesive whole, for example, linking the issues at the materials level to the final devices and their performance.

The unique materials properties of SiC make it possible to develop power devices up to 10 kV (herein defined as HV), or up to 30 kV (UHV). This technology space is likely to be an enabler for traction, industrial machines, solid-state transformers, for HVDC and for many other applications. Yet, HV and UHV devices are still largely the preserve of the research institutes; the chip manufacturers and hence their supply chain are chasing the lucrative electric vehicle market accessed at the medium voltage 600-1700 V range. However, this demand is driving up material quality, lowering costs and advancing epitaxial processes, all advances that make high voltage devices more viable.

The supply chain in SiC power electronics divides into a number of distinct activities, three of which shall be the focus of this report. Two elements of the supply chain, the **production and supply of SiC substrates**, and the **epitaxial growth process** are the subject of the first part of this report in Section 2. These subjects have significant overlap and commonality, both concerning the cost and quality of the underlying SiC material, which would ideally be produced on a large scale, free of defects that cause issues in HV devices, and with a fast growth process.

The third element of the supply chain considered in this report, in Section 3, is the **design and fabrication of HV/UHV SiC power devices**. These include in the HV class, unipolar **MOSFET** transistors and **Schottky diodes**, both of which have been developed successfully in the medium voltage range, but scaled up to work effectively at the elevated voltage class. In the UHV class, bipolar devices, **IGBTs** and **thyristors** must be introduced, as well as **Superjunction MOSFETs**. These devices will be familiar to the Si power device user, but are not yet being widely considered in SiC, beyond the academic and research circles. They each pose their own challenges, stemming from the underlying material, and the complex fabrication procedures. Common to the HV and UHV classes is the need to develop **termination strategies** that allow the device to withstand the rated voltage. Yet at high voltage, these structures consume significant space. Hence, the state of the art in HV/UHV termination design is explored.

Other elements of the supply chain are not considered here. Device packaging, circuit design and applications are beyond the remit of this report, but are important elements addressed elsewhere.

Throughout the report, a number of Tables are presented to summarise the main suppliers or manufacturers of a certain element of the chain. At the end of the report in Sections 4 and 5,

the research institutes and the companies who are particularly active in HV/UHV device development are listed for reference.

The report makes use of a number of hyperlinked sources. These are used to link to online resources with further information, but also in place of a reproduced Figure, for which the rights holder will demand a fee. Fortunately, one of the biggest journal providers, the IEEE, allow all their images, graphs and figures to be reproduced on semanticscholar.org, and hence many of the links lead there.

Traditional academic-style referencing is used throughout, such that the reader may find the original sources. These papers can usually be downloaded for a small fee form the publisher. The review articles highlighted in each Further Reading section are worth purchasing as an addendum to this report. Links are provided where freely available online sources of these papers are available.

Finally, this is an exciting time to be considering HV and UHV SiC technology. The reports referenced throughout suggest that this is a maturing technology, which has significant potential to be captured by a company willing to focus and invest in this area.