SiC power devices: if only we had a switch...

With 4" diameter substrates and zero-micropipe technology now introduced, Dr Philippe Roussel of market research firm Yole Développement considers what else remains in the path of SiC power device market development.

With January's introduction of 4" diameter SiC substrates coupled with ZMP (Zero MicroPipe) technology from the acquisition of IntrinSiC Semiconductor Corp of Dulles, VI, USA in July 2006, Cree of Durham, NC, USA is now marketing a product able to match power device makers' main requirements. However, few of them have yet entered the production phase and, apart from Cree itself and Infineon, no other players are commercially active in this segment.

SiC material cost and small wafer diameter are always stated as constraints on the level of interest from the big players in the power device sector. So, now that these two factors are being resolved, the prospect of developing a SiC switch is not so far off.

Making money from SiC devices: myth or reality? Market data tells the tale....

Let's be frank: SiC device manufacturing is not yet the most exciting money-making activity. Neither Cree nor Infineon issue explicit figures, but we estimate that sales of SiC-based power electronic devices generated revenues of about $15m in 2006 (Cree reported $17m for both SiC power devices AND wide-bandgap RF devices, while Infineon does not give any details).

The only product that is commercially available is the Schottky barrier diode (SBD), which is now reaching the 1200V and 20A range. This component targets many possible applications (Figure 1), but it is mostly used in high-end PFC (power factor correction) systems where it brings some impressive added value, such as better power conversion efficiency (Cree have demonstrated a 50% improvement in losses), shrinkage of circuit board size, avoidance of RF oscillation, and the elimination of many passive discrete devices.

Theoretically, SiC can be considered as the ideal technology for replacing silicon-based circuits in PFC systems. Moreover, we are talking here about a total accessible market of more than 1.3 billion PFC units in 2006, facing a compound annual growth rate of 12% according to the Darnell Group. The top 3 PFC manufacturers (Delta Electronics, Astec Power/Emerson and Lite-on Technology) generate over $2.8bn in revenues.

So, why are annual sales of SiC devices only $15m? The first reason is certainly linked to technology implementation: it is not a chip-to-chip replacement. PFC circuits have to be re-designed to handle and exploit the added value of SiC Schottky diodes. Secondly, from an economics point-of-view, the PFC market is heavily price-pressurized and the introduction of a new technology is a potential risk that some companies are hesitant to take. Finally, the market price for SiC Schottky diodes is a limiting factor.

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A cost breakdown for SiC Schottky diodes is significant in order to illustrate this last point (Figure 2). To summarize, the bill of materials accounts for about 75% of the total device cost (based on production using existing 3" wafers). This is fundamentally different from silicon-based technology, where material is no more than 10%. The advent of 4" SiC material should help to reduce this ratio. Cree has already introduced 4" wafers into its device production, and Infineon may complete the 3" to 4" transition by Q3/2007.

The current market price for SiC Schottky diodes is oscillating somewhere between $0.30/Amp and $0.40/Amp, depending on the voltage and lot size. According to both SiC device makers and PFC manufacturers, it seems that a price level of $0.20/Amp would give favorable feedback for technology penetration. The first estimates for 4"-based SiC manufacturing cost lead us to think that this threshold should be beaten by 2008, assuming improvements in production yield, reduction in SiC wafer price ($0.15/mm^2 would be well received) and increases in fab capacity.

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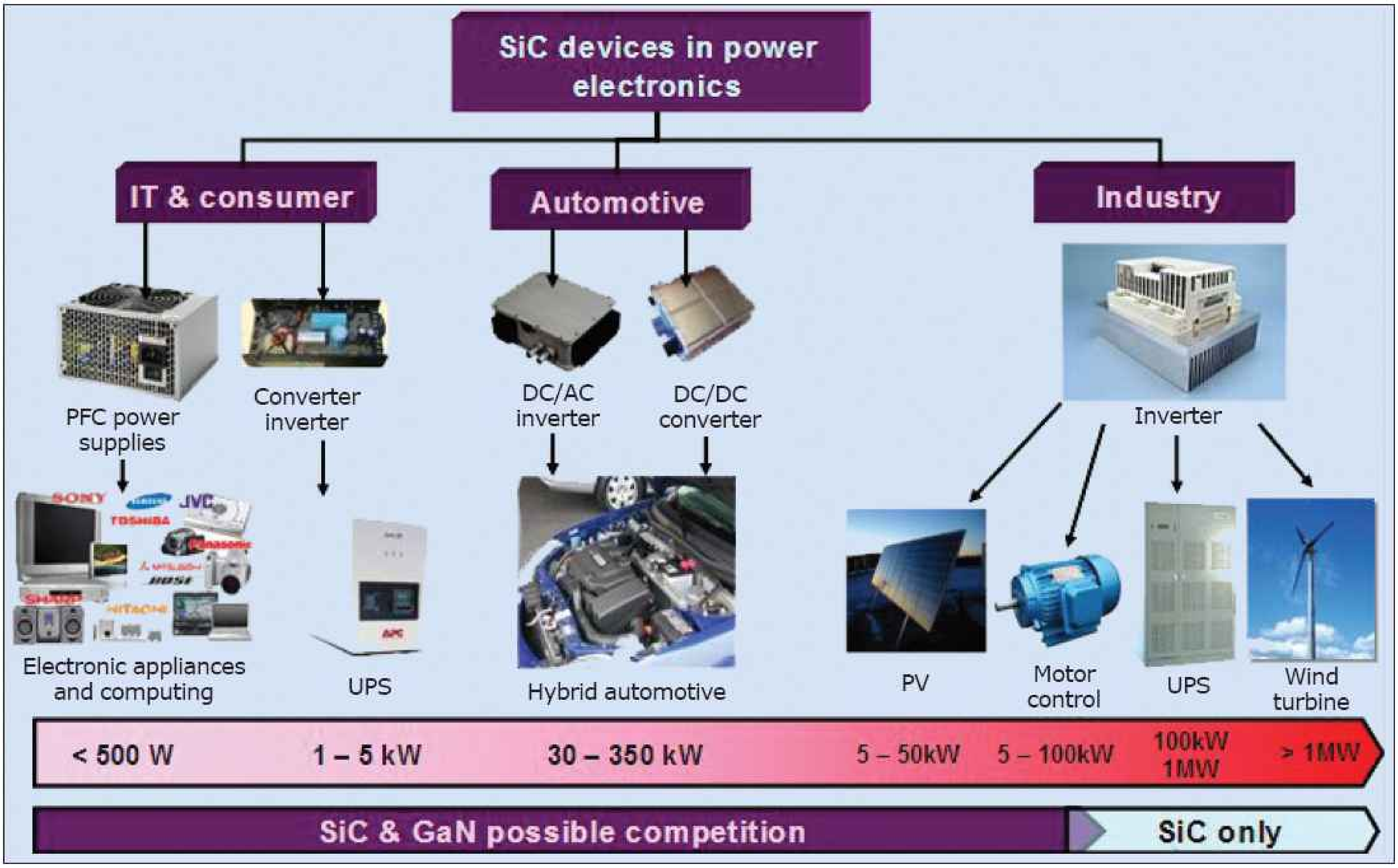

Figure 1. Possible applicative fields for SiC power devices.

What are the historic 'Godzilla's' doing with silicon carbide?

Another parameter could boost the SiC device market: the expansion of the competitive landscape and the involvement of new players. The silicon rectifier market is led by firms such as Vishay, Shindengen Electric, STMicroelectronics and MicroSemi, who already supply PFC manufacturers in large volumes and benefit from established commercial networks linking to end users.

The strategies of the above device manufacturers regarding SiC are as follows:

- Vishay in 2000 acquired the SiC technology of DaimlerChrysler AG (which the latter had been developing since 1993). Most recently, in November 2006, Vishay bought International Rectifiers' Power Control Systems (PCS) division, in which SiC developments have been achieved.
- Shindengen Electric of Tokyo, Japan is active in SiC technology and has published many papers on the topic.
- STMicroelectronics has been developing SiC Schottky diodes for many years at its R&D center in Tours, France. The firm's Italian manufacturing plant in Catania, Sicily may be used for devices production.
- MicroSemi acquired APT (Advanced Power Technology Inc) in April 2006 and has since established a production capability in Bend, OR, USA.

So, SiC device manufacturing plans are moving rapidly, and further announcements are expected by late 2007.

The ultimate target: a SiC switch

Diodes and switches coexist quite well together and, even if a hybrid SiC–silicon approach is an option, full SiC electronics is highly desired for many applications.

To highlight this, hybrid electrical vehicles (HEVs) currently use silicon-based insulating-gate bipolar transistors (IGBTs) and diodes in their inverter module to power the (30–50kW) electric motors. This silicon chipset has to be cooled down by a water-based system to maintain a device junction temperature of about 85°C. However, this requires a dedicated water-cooling system, separate to the

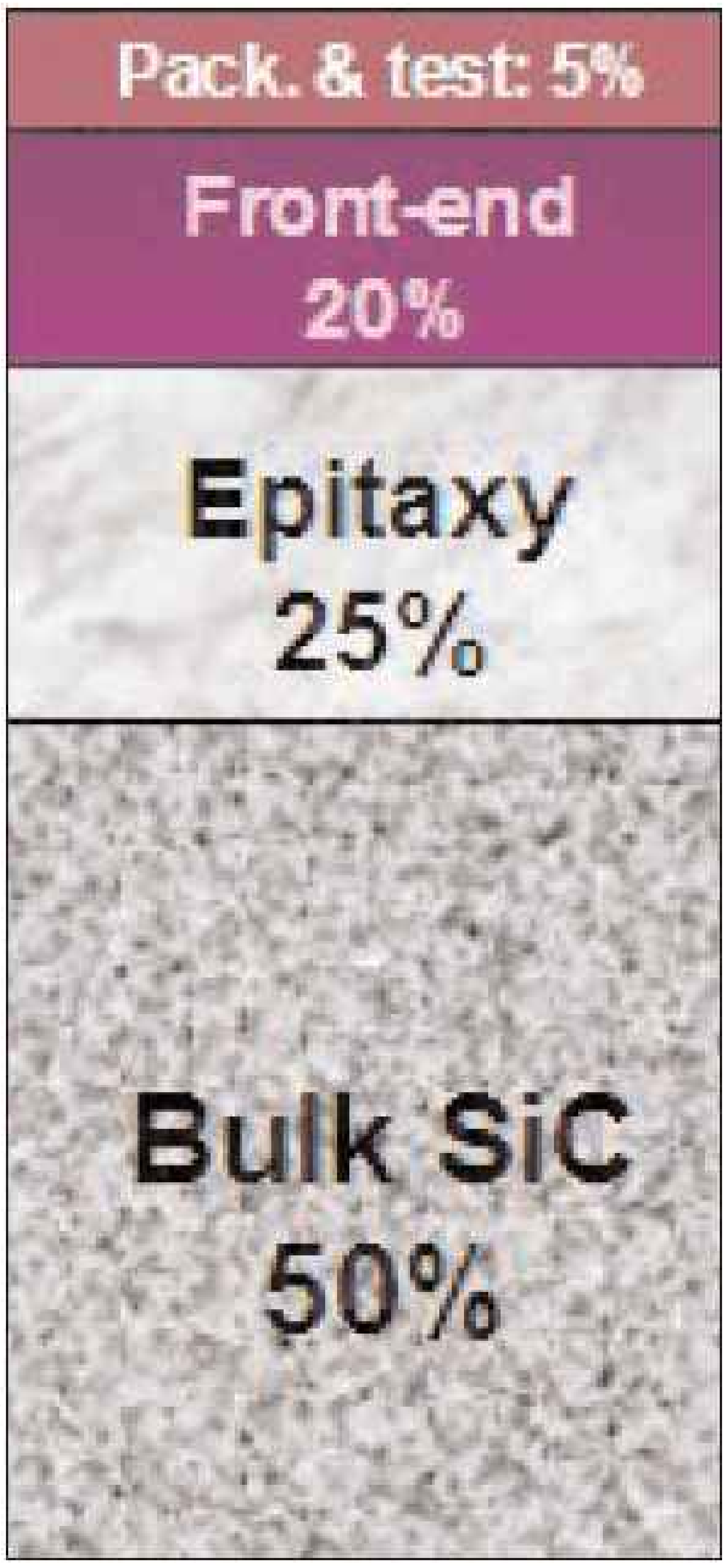

Figure 2. Cost breakdown for SiC Schottky barrier diode.

Table 1. Involvement of key players in SiC switch development.

	MOSFET	JFET			BJT	IGBT
Company		**Normally-on**	**Normally-off**	**Cascode**		
Acreo (SW)	x					
Denso (J)	x					
Cree (US)	x	x			x	x
Fuji (J)	x					x
GE (US)	x					
Hitachi (J)	x					x
Matsushita MEI (J)	x					
Mitsubishi (MELCO) (J)	x					x
Nissan Motor	x					
Northrop Grumman (US)	x	x	x	x (full SiC)		
Oki Electric (J)	x					
Philips (NL)	x					
Rohm (J)	x					x
Semisouth (US)		x	x			
Rockwell (US)		x				
SiCED (D)	x	x		x (hybrid Si–SiC)		
Toshiba (J)	x	x				x
Sumitomo SEI (J)		x				
TranSiC (SW)					x	
United Silicon Carbide (US)		x	x		x	

cooling system in charge of the fuel engine, which can handle higher temperatures. One of the objectives of HEV vehicle makers is to simplify this setup by implementing SiC-based electronics that can easily withstand 150°C or more. This would then allow the use of a single water-cooling system rather than two. This way, a money saving of about 15% on the power module could be achieved. However, this approach only applies for a full SiC electronics chipset, and would not be realistic with a hybrid solution.

In terms of the requirements for this particular application, 1200V/100A SiC single chips would fit perfectly.

Up to now, the main R&D effort has been oriented towards SiC MOSFETs (metal–oxide–semiconductor field-effect transistors). Lots of announcements have been made (by Rohm, Cree, Acreo, Toshiba etc). However, in summary, oxide reliability and poor electronic mobility issues remain partially unsolved.

As shown in Table 1, even if the MOSFET remains the most-studied device, alternatives exist, and the JFET (junction gate field-effect transistor) or BJT (bipolar junction transistor) are also within the scope of some prestigious R&D groups.

The common characteristic of the JFET and BJT is that, unlike the MOSFET, it does not use any oxide layer. Recent results from SemiSouth, TranSiC and GeneSiC have been very encouraging: TranSiC is now fine tuning a 1200V, 6A BJT chip with an operation temperature up to 250°C; SemiSouth is focusing on a normally-off version of a SiC JFET; and GeneSiC is concentrating on very high power SiC devices, including MOSFETs and JFETs. It also has to be noticed that Infineon has announced its intention to produce a SiC JFET in large volume in the very near future. Also, in early 2006, Rohm released results concerning a SiC MOSFET that can withstand a voltage of 900V and has an on-resistance (R_{on}) of 3.1mΩ/cm^2.

Conclusion

It is now clear that the relative stagnation of the SiC power device market is partly due to the lack of reliable transistor technology. The PFC sector is the only one driving SiC device sales, and prospects for higher market penetration are linked mainly to a drop in device cost. In addition, others applications demand a complete SiC-based switching cell (i.e. a diode and a transistor).

MOSFETs have largely been investigated by major SiC R&D teams. However, it seems more and more certain that JFET or BJT technologies may be first to be released onto the market. So, with big-name manufacturers confessing to facing unresolved problems with MOSFETs, maybe the future is one free from oxides.

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