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Partnering for the Safe Supply of Industrial Power Modules

Power semiconductor users are painfully aware of the challenges faced in recent years due to an uncertain supply chain. Therefore, "multiple sourcing" has always been a desire when designing a power converter. Semikron Danfoss, as the largest chip-independent power module manufacturer, is in a unique position to address this. Together with our long-time partner ROHM Semiconductor, we add a fully compatible new source of 1200V IGBT to our low power module offering. This will further help to mitigate power module delivery shortages and secure the supply chain.

By Paul Drexhage, Technical Marketing Manager, Semikron Danfoss

The worldwide growth in electrification technologies has created unprecedented demand for power modules. Often, it is the chip supply that limits power module availability. Despite ongoing investments in production capacity by the chip manufacturers, the supply situation remains tight. It is against this backdrop that ROHM has introduced the new 1200V RGA IGBT, targeted as an alternative to the latest Generation 7 IGBT devices in industrial applications. For years, ROHM has been a trusted partner to Semikron Danfoss for the supply of silicon carbide devices. ROHM is now expanding their silicon bare die offering to Semikron Danfoss, positioning themselves as an advanced alternative to traditional chip suppliers.

The RGA is a newly designed, light punch through, trench gate IGBT with $T_{j,max}$ = 175°C. The conduction, switching, and thermal characteristics are optimized for new industrial drive applications in the low to medium power range. At the same time, the RGA is intended to remain compatible with existing IGBT solutions, enabling a multiple source approach. The following discussion shows this with a comparison of basic device characteristics between two otherwise identical modules. The 1200V RGA IGBT has been tested in the baseplate-less MiniSKiiP package. A Generation 7-equipped SKiiP24AC12T7V1 (I_{Cnom} = 35A) is used as the reference. In both test modules, the circuits are identical and use the Semikron Danfoss CAL4F freewheeling diode.

Static behavior
The RGA's modern trench gate design and selected carrier profile are designed to give a low on-state voltage drop. As with all modern silicon IGBTs, the RGA exhibits a positive temperature coefficient (PTC) for forward voltage drop over the higher end of the current range. While this PTC characteristic is stronger in the RGA than the Generation 7 IGBT, the slightly higher resulting forward voltage drop at high temperatures is partially helped by a lower voltage drop at room temperature (Figure 1). The result is similar forward voltage drops for both IGBTs at rated current, with the RGA device being with ±4% of the Generation 7 device over the given temperature range. Overall, like the Generation 7 IGBT, the RGA demonstrates a much lower forward voltage drop than previous chip generations.

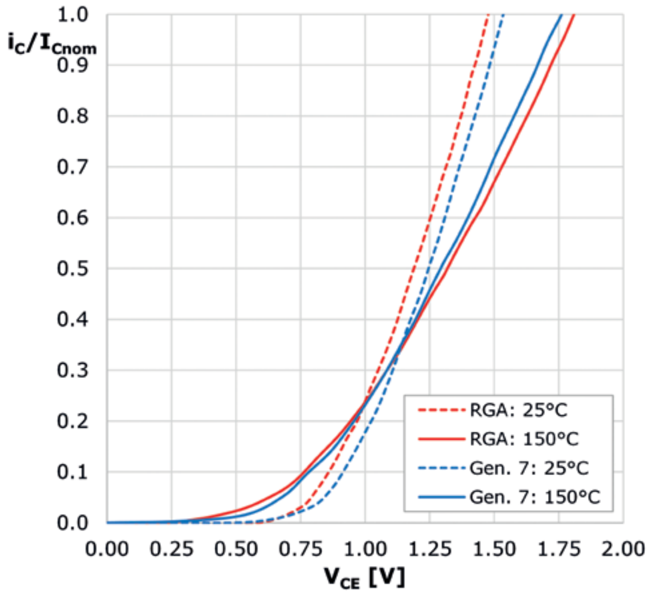

Figure 1: Forward characteristics (chip level), scaled to nominal current

The high current behavior of the RGA IGBT differs from the Generation 7 IGBT. As shown in Figure 2, the RGA IGBT comes out of saturation at a higher current. This allows for better handling of transient currents that occur in applications with frequent overloads such as motor drives. Even with the temperature coefficient impacting behavior at 150°C, the RGA device can still handle peak currents of three times the nominal rating. This potentially allows for modules with a peak repetitive current rating of $I_{CRM} = 3 \times I_{Cnom}$, which is suitable for applications with expected step overloads.

For additional overload capability, the RGA IGBT equipped power modules allow for the same high temperature operation as Generation 7 chipsets: periodic operation up to the maximum chip rating of 175°C is permitted. Details of the allowed temperature profile are given in section 2.3 of [1]. For continuous operation, the RGA IGBT-equipped power modules follow the same guideline as existing devices: 25K margin from the absolute maximum junction (i.e. $T_{j,op}$=150°C).

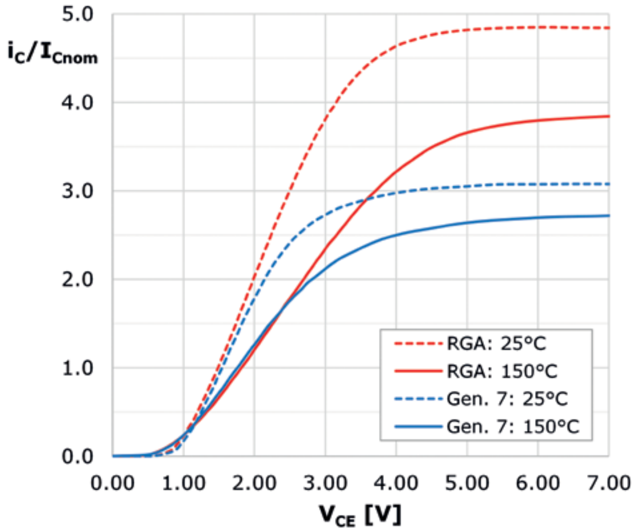

Figure 2: High current forward characteristics (chip level), scaled to nominal current

Gate characteristics

Generation 7 IGBT employs a striped trench gate structure to achieve a very small IGBT cell pitch and high electrical conductivity (i.e. low voltage drop). However, a drawback to this structure is that it presents a significantly higher gate capacitance compared to e.g. IGBT 4. This high capacitance results in a high load (current) requirement for the driver circuit when switching. The well-proven, conventional trench gate structure employed in the RGA IGBT gives an 18% smaller gate charge than the equivalent Generation 7 IGBT device. At the same time, the gate threshold voltage, $V_{GE(th)}$, remains similar (e.g. 6.0V) to other modern IGBTs, providing a fair balance between parasitic turn-on resilience and ease-of-driving. The recommended gate drive voltage is also the same as most IGBT devices, with testing having been carried out with $V_{G,on}$ = 15V and $V_{G,off}$ = -8V.

Dynamic behavior

Newer generations of IGBT tend to exhibit higher dv/dt levels (e.g. in excess of 7kV/µs) because of the efforts to reduce switching losses through increasing the speed of the turn-on and turn-off processes. The RGA is no different, but like the Generation 7 IGBT, the turn-on dv/dt and di/dt can be controlled by varying the gate resistance. dv/dt levels acceptable to motor drive applications (e.g. <5kV/µs) are achieved, particularly at higher currents. In general, a higher R_{Gon} value is required for the RGA to meet similar dv/dt and di/dt values to Generation 7 devices (Figure 3).

The effect of this higher speed switching and the role of the gate resistor is apparent when examining the turn-on process of the RGA and Generation 7 IGBTs under the same conditions and with the same gate resistor (R_{Gon} = 8.2Ω, Figure 4). In this situation, the peak current on the RGA device is approximately 22% higher than on the Generation 7 device. However, the high di/dt, coupled with the fast drop in collector-emitter voltage, mean that the current-voltage product and resulting switching losses are lower. If the high dv/dt can be tolerated, such as in high-speed servo drive applications, the reward is a 25% reduction in turn-on energy when using the RGA IGBT.

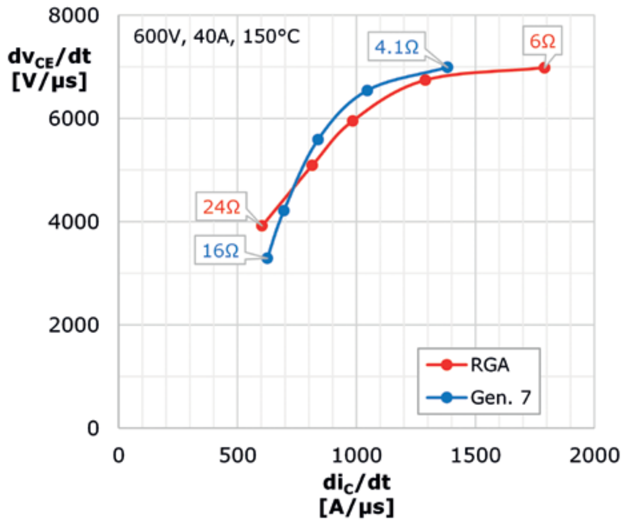

Figure 3: Turn-on dv/dt and di/dt characteristics, with varying R_{Gon}

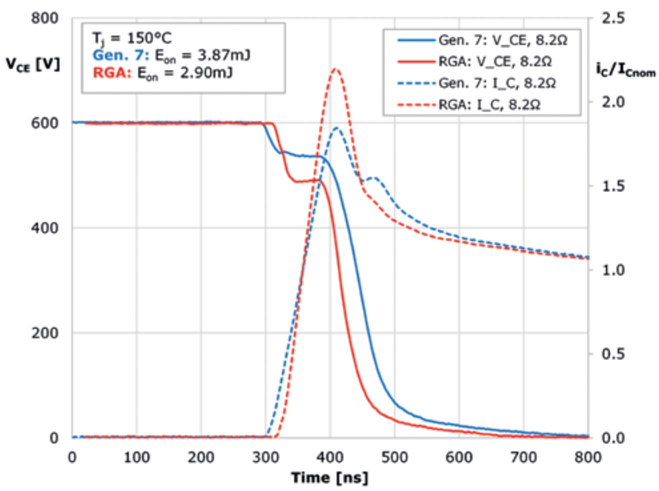

Figure 4: Turn-on behavior with same R_{Gon}, current waveforms centered at I_{Cnom}

Conversely, if switching speeds similar to a Generation 7 IGBT are required, doubling the turn-on gate resistance gives very similar behavior. Figure 5 demonstrates that smooth, nearly overlapping, voltage and current waveforms are achieved with an increased gate resistance (R_{Gon} = 16Ω). The slower switching speed increases losses, but in this example the turn-on energies in the RGA and reference Generation 7 device are nearly identical.

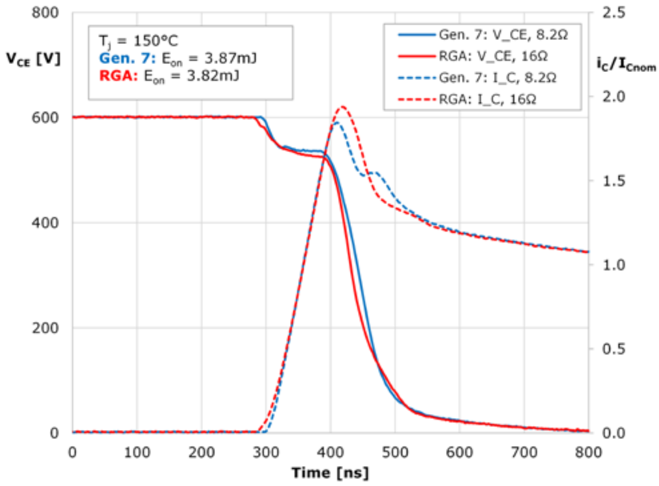

Figure 5: Turn-on behavior with different R_{Gon}, current waveforms centered at I_{Cnom}

Generation 7 IGBTs, as with most modern trench-gate IGBT designs, are less responsive to the effect of small changes in the turn-off gate resistance. This is also true for the RGA IGBT, where adjusting the resistor over a ~20Ω range produces little change in the di/dt, dv/dt, and turn-off energy. A side-by-side comparison to the Generation 7 IGBT during turn-off using the same 8.2Ω gate resistance shows nearly identical voltage overshoot despite a rapid rise time (Figure 6). The RGA IGBT exhibits a soft, but long, current "tail" that increases the voltage-current product. However, this effect is partially compensated by the higher dv/dt. The net result is that the turn-off energy in the RGA is only 5% higher than in the reference Generation 7 device.

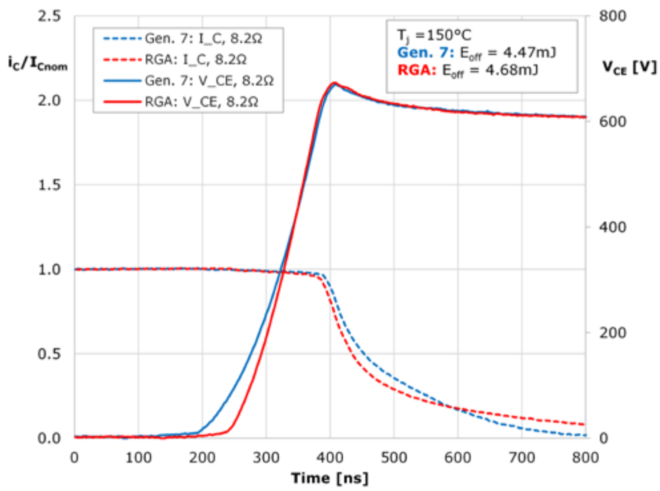

Figure 6: Turn-off behavior with same R_{Gon}, current waveforms centered at I_{Cnom}

Application comparison

The net effect of conduction losses, switching losses, and thermal performance is best indicated by calculating the resulting junction temperature for a given application conditions. In this case, a three-phase, 2-level voltage source inverter circuit is considered with a sixpack MiniSKiiP module and the application parameters given in Table 1. Two modules with a nominal current rating of 35A are selected for comparison. This size of module would be suitable for an industrial motor drive in the 5.5-11kW range, depending on the considered overload profile.

DC Voltage, V_{DC}	650V
Line-Line Voltage, V_{out}	400V
Power Factor, cos(ϕ)	0.85
Fundamental Frequency, f_{out}	50Hz
Output Current, I_{out}	25.9A_{rms} (P_{out} = 15.3kW)
Switching Frequency, f_{sw}	Variable
PWM	Sine-Triangle
Junction Temperature, T_j	Variable
$R_{th(s-a)}$	0.1K/W
Ambient Temperature, T_a	45°C
Junction-Sink Thermal Resistance, $R_{th(j-s)IGBT}$	0.80K/W (RGA)
	0.93K/W (Gen. 7)
R_{Gon}	16.4Ω (RGA)
	8.2Ω (Gen. 7)
R_{Goff}	13.7Ω (RGA)
	8.2Ω (Gen. 7)

Table 1: Parameters for example thermal calculation

For this comparison, Semikron Danfoss' proven SemiSel calculation tool, now in its fifth generation, is used. A single MiniSKiiP module is mounted using High Performance Thermal Paste (HPTP) onto a hypothetical, forced air-cooled heatsink with 45°C air. The junction temperature is calculated with the inverter circuit operating under the parameters given in Table 1. Based on the earlier discussion, a higher turn-on gate resistor is chosen for the RGA IGBT to give a similar dv/dt behavior as the Generation 7 IGBT. A current is selected that gives a junction of 125°C junction temperature for the highest chosen switching frequency. This temperature is considered a typical continuous limit for sizing modules in motor drive applications due to power cycling lifetime concerns. The resulting junction temperature and efficiency versus frequency are plotted in Figure 7.

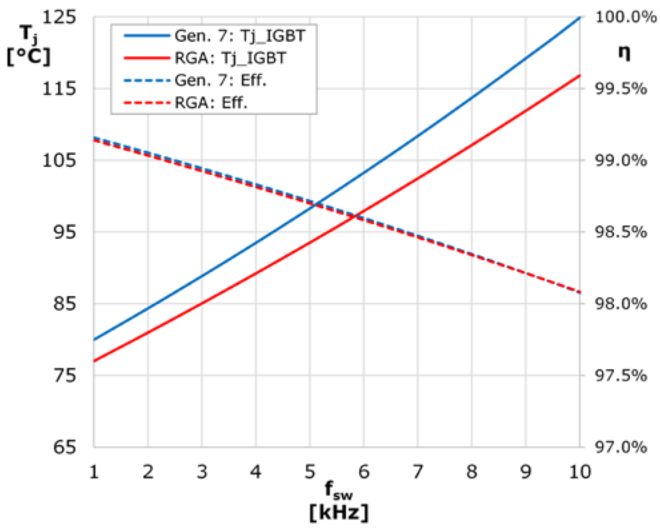

Figure 7: Calculated junction temperature and efficiency for a fixed output current

Under the same operating conditions, the calculated RGA IGBT junction temperature is, on average, 6K lower than that of the Generation 7 IGBT (solid lines in Figure 7). This is primarily the result of the optimized chip size of the RGA IGBT which results in a 14% lower thermal resistance from junction to heatsink. A lower junction temperature yields lower thermomechanical stress in the power module and potentially increased power cycling lifetime. If a similar junction temperature is acceptable with the RGA IGBT, reduced cooling effort is required. This could be in the form of a lower cost heatsink or reduced fan speed.

The higher forward voltage drop of the RGA at high temperatures impacts efficiency at low switching frequencies where conduction losses are dominant. Conversely, the reduced turn-on energy of the RGA gives it an edge in efficiency at higher switch frequencies. However, in the given application example the semiconductor efficiencies for the two chips are essentially the same over the range of 1…10kHz (dashed lines in Figure 7).

Alternatively, it might be desirable to use the superior thermal performance of the RGA to achieve more output current in the same package. A separate thermal calculation has shown that the RGA IGBT is capable of 2…9% higher output current than the Generation 7 IGBT in the 1…10kHz range, at the cost of a slightly reduced efficiency.

Short circuit behavior

The general trend towards smaller chip sizes has reduced the thermal capacity of modern IGBT dies and hence the short circuit capability compared to older IGBT chip generations. The 1200V RGA IGBT maintains the present standard of pulsed short circuit withstand time, t_{psc}, of 8µs at 800VDC, 150°C that is also shared by Generation 7 IGBT. The high di/dt of the RGA IGBT means that it also reaches high peak currents during short circuit events, above five times I_{Cnom}. Despite this, the turn-off behavior remains controlled, without any high frequency oscillations.

Humidity robustness

As power converter deployment expands into new applications around the globe, more power semiconductor devices are likely to be subjected to high humidity environments. This, combined with a better understanding of device failure modes has pushed the industry to more stressful qualification tests. In particular, the High Voltage, High Humidity, High Temperature Reverse Bias (HV-H^3TRB) test has become the standard for measuring long term humidity robustness. This test stresses the edge termination structure of an IGBT chip by applying 80% of rated blocking voltage (e.g. 960VDC) in a test chamber at 85°C air temperature with 85% relative humidity. Devices are evaluated based on how many hours (e.g. 168/504/1000h) they can withstand this environment without exceeding leakage current limits for a given blocking voltage. Testing by Semikron Danfoss has shown the RGA IGBT can meet the 1000h minimum, which puts it in the same class as Generation 7 IGBT.

Implementation

Semikron Danfoss can offer the 1200V RGA IGBT in a full range of nominal current classes from 10A to 150A. This range, combined with the suitability of the RGA chip for motor drive applications, means that the MiniSKiiP family is the ideal choice for module implementation. The baseplate-less, spring-contact MiniSKiiP is already deeply embedded in the worldwide motor drive market and always equipped with the latest generation IGBTs. Therefore, it is important for this product to have an alternative IGBT source to diversify the supply chain. The uniform-height MiniSKiiP housing family (Figure 8) is also offered on the market as a multiple source package, making an alternative IGBT a valuable option for manufacturers. The first RGA-equipped MiniSKiiPs will be available in sixpack ("AC") and converter-inverter-brake ("NAB") topologies to allow for pin-compatible replacements to Generation 7 IGBT equipped modules. The MiniSKiiP is available with the same pre-applied High Performance Thermal Paste (HPTP) used in the calculated application comparison.

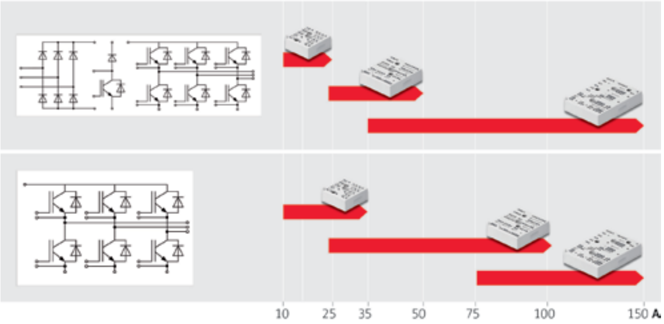

Figure 8: RGA-equipped MiniSKiiP 1/2/3

For press-fit/solder applications, the industry-standard SEMITOP E package will also be available in pin-compatible configurations to existing Generation 7 IGBT module offerings. This housing family (Figure 9) will also offer sixpack ("GD") and converter-inverter-brake ("DGDL") circuit configurations. The SEMITOP E package is fully compatible to other industry standard offerings, despite giving an advantage in the form of integrated mounting

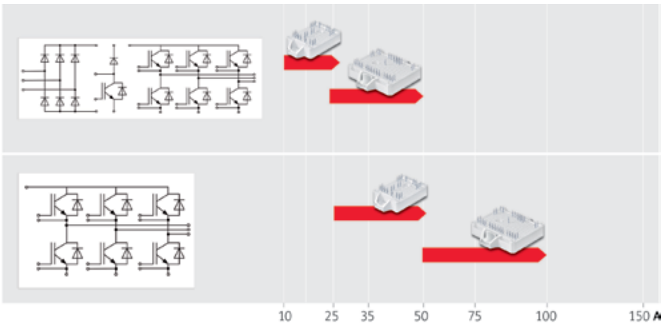

Figure 9: RGA-equipped SEMITOP E1/E2

tabs instead of metal clips. These give increased mounting pressure, resulting in lower thermal resistance. The superior enhanced press-fit pin features an internal strain relief for higher mechanical mounting robustness. The SEMITOP E is available with pre-applied HPTP or the new Semikron Danfoss exclusive pre-applied High Performance Phase Change Material (HP-PCM) for ease-of-handling during assembly. The 1200V RGA IGBT will be indicated by the "12RA" nomenclature in the power module description: e.g. a MiniSKiiP CIB module with a 35A nominal current rating will be named SKiiP 24NAB12RAV1.

Conclusion

The power electronics industry continues to recover and learn lessons from the supply issues in recent years. It's clear that diversification in both semiconductor chip and module manufacturing is required to generate true "multiple source" power modules. In the case of 1200V Generation 7 IGBTs, a reliable equivalent from a reputable manufacturer is now available to address this issue also in the low power range. The 1200V RGA IGBT from ROHM is a perfect alternative to the Generation 7 IGBT and can be made to behave in a remarkably similar manner with small gate resistor adjustment. Slight differences in conduction losses are completely compensated by improved thermal performance. This makes the 1200V RGA IGBT's performance in the application fully compatible with the latest Generation 7 IGBTs available in the same power module packages. With humidity, short-circuit, and temperature robustness, the 1200V ROHM RGA IGBT is positioned to be a highly reliable choice when packaged in Semikron Danfoss power modules.

References

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