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IGBT With Intrinsic Body Diode Improves Performance Of Single-Ended-Resonant Inverters In Induction Heating Applications

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Nowadays the field-stop IGBT provides lower saturation voltage drop and lower switching losses than the conventional non-punch-through (NPT) IGBT, making the field-stop IGBT well suited for induction heating (IH) applications. A relatively recent improvement in the field-stop IGBT—the integration of an anti-parallel diode on the IGBT die through use of the shorted-anode technology—made the field-stop IGBT even better for IH designs.

But further enhancements in the field-stop shorted-anode IGBT are possible as we explain in this article. Here, we introduce Fairchild's second-generation field-stop shorted-anode trench IGBT with intrinsic body diode. This latest generation IGBT is offered in voltage ratings ranging from 1100 V to 1400 V, which align closely with the requirements of induction heating.

After discussing the requirements of IH applications, we describe the structure and characteristics of the new IGBT that make it most effective in single-ended-resonant inverters used in IH designs. Specifically, this latest-generation IGBT enables designers to achieve better inverter performance at higher switching frequencies, which ultimately enables better heating efficiency. Experimental results presented at the end of article confirm the advantages of the new IGBT in the intended applications.

The Single-Ended-Resonant Induction Cooker

Since induction heating directly heats a cooking vessel, it has many advantages over other cooking methods associated with a traditional stove (electrical coils, burning gas). Some of these advantages include rapid heating, improved thermal efficiency, precise heat control, and a stove that is easy to clean.

For induction heating or cooking, a high-frequency resonant inverter is required to convert the electrical energy into heat energy within a ferromagnetic metal vessel. Basically, two types of resonant inverters, a half-bridge (HB) inverter and a single-ended (SE) inverter can be considered. Of these two inverter types, the SE resonant inverter is generally more popular in induction heating applications due to its lower cost structure as well as its relatively high efficiency. Fig. 1 is the basic block diagram of an SE-resonant induction cooker.

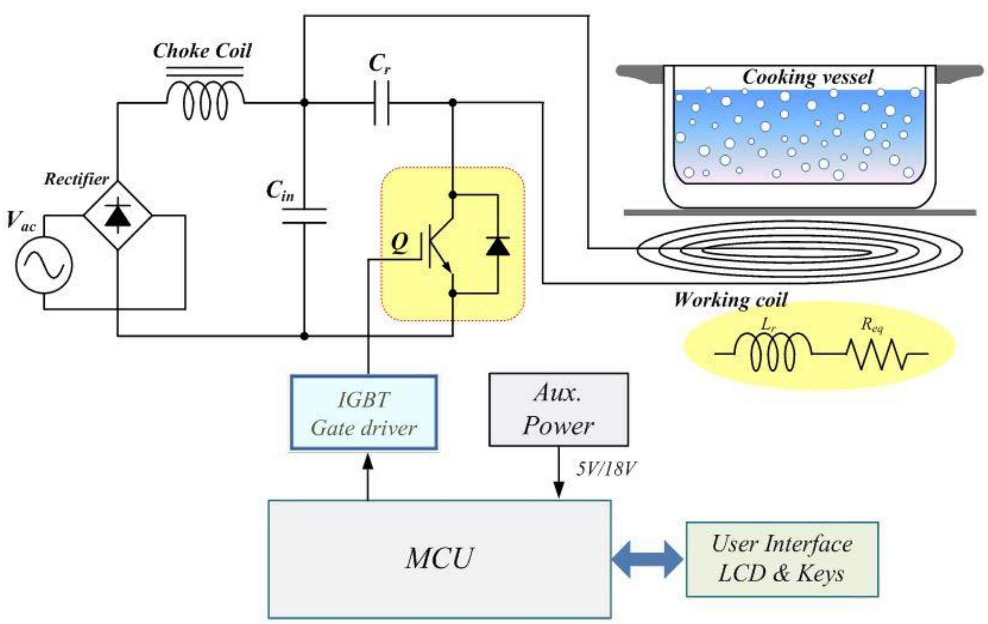

Fig. 1. Block diagram of a single-ended resonant induction cooker.

The rectifier, choke coil, and input capacitor (C_{in}) shown in Fig. 1 comprise a low-pass filter (*LPF*). Meanwhile, the working coil can be represented as a series combination of inductance (L_r) and resistance (R_{eq}), which combine with capacitor C_r to form a resonant tank circuit.

The IGBT (*Q*) in the SE-resonant inverter is turned-on in the zero-voltage switching (ZVS) condition by the freewheeling current and turned-off in the quasi-ZVS condition using a voltage resonance that is much higher than the input voltage. In order to turn on the IGBT in the ZVS condition, an anti-parallel diode is required even though it only commutates for a short period. During the off period, the voltage resonance between L_r and C_r occurs, requiring a much higher breakdown voltage of the IGBT than the input voltage. Generally, 1000-V to 1600-V IGBTs are used in SE-resonant inverter applications.

In terms of efficiency, the IGBT of an SE-resonant inverter should have values for the turn-off energy (E_{off}) and the saturation voltage drop ($V_{ce(sat)}$) that are as low as possible given that lowering E_{off} results in higher $V_{ce(sat)}$ and vice versa. A field-stop trench (FST) IGBT has lower E_{off} and $V_{ce(sat)}$ at the same time compared with a conventional NPT IGBT of the same die size. For this reason, an FST IGBT is very suitable as a switching device for IH applications.

Recently, a new idea emerged—a shorted-anode IGBT (SA IGBT) that allows embedding of the body diode into an IGBT in the same fashion as a MOSFET. Fig. 2 shows the basic structure of an SA IGBT where the n+ collector directly contacts the field-stop layer and acts as a cathode of a PN diode, while the p+ collector layer acts as the general collector of the FST IGBT. For a given-sized package, this SA IGBT has an enhanced current capability because the intrinsic body diode eliminates the need for co-packaging of an anti-parallel diode, freeing up space so that there is room for a larger IGBT die. Moreover, this new IGBT offers a lower cost structure, both in terms of die cost as well as the cost of assembling a single die for the IGBT versus two die when the separate diode is required.

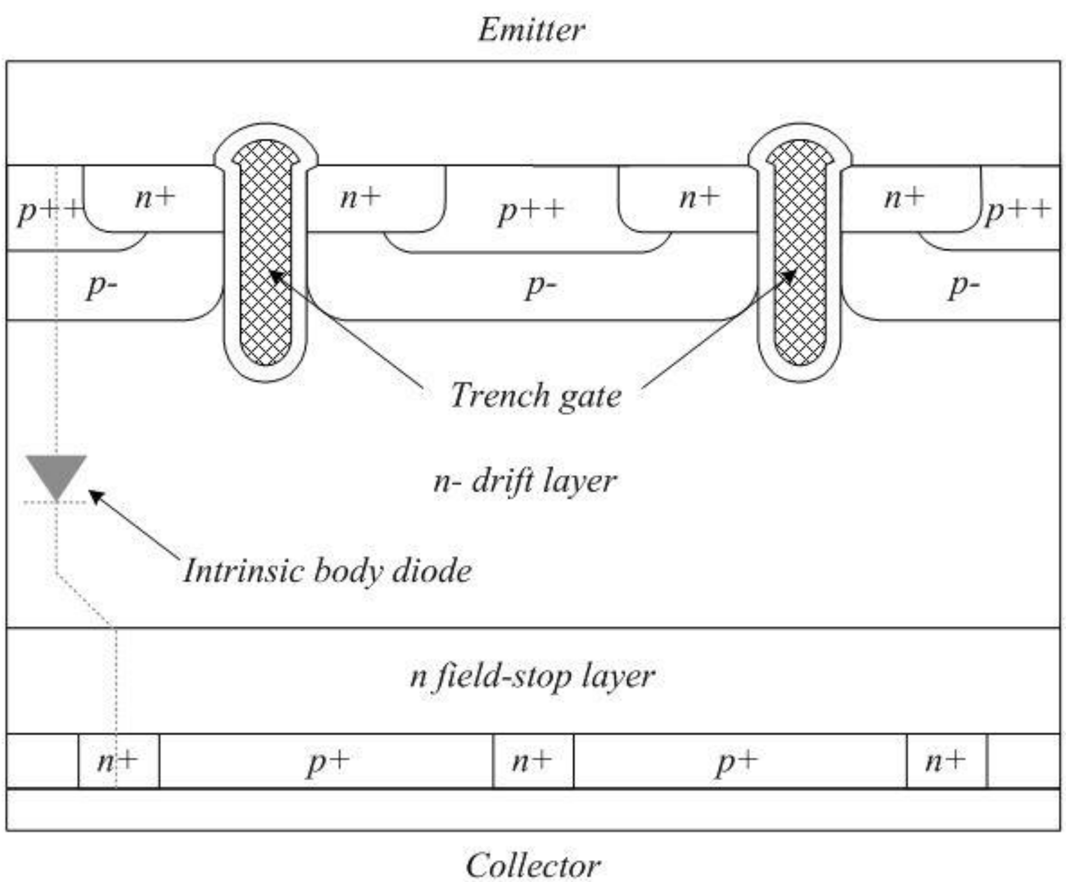

Fig. 2. Field-stop shorted-anode trench IGBT.

Fairchild recently released the second-generation SA IGBT with a range of 1100 V to 1400 V for the breakdown voltage (BV_{CES}); the previous version only offers a breakdown voltage of 1200 V. The entire lineup of first- and second-generation SA IGBTs with comparisons of their key parameters is shown in Table 1. With an advanced field-stop technology, the second-generation also has highly improved switching performance compared to the previous SA IGBT, though $V_{ce(sat)}$ is a little bit higher. Consequently, the second-generation SA IGBT will be more advantageous as the switching frequency is increased.

Table 1. Field-stop shorted-anode trench IGBT line-up.

Generation	Part Number	BV_{CES} (V)	I_C (A)	$V_{CE(sat)}$ @15 V (V)	E_{off}* (µJ/A)	Pkg.	Sys. Input (V)
1st Gen.	FGA20S120M	1200	20	1.55	28.52	TO-3P	220
2nd Gen.	FGA50S110P	1100	30	1.8	14.84	TO-3P	110
	FGA15S125P	1250	15	2.25	18.18	TO-3P	220
	FGA20S125P	1250	20	2	16.57	TO-3P	220
	FGA25S125P	1250	25	1.75	15.94	TO-3P	220
	FGA30S120P	1300	30	1.75	17.42	TO-3P	220
	FGH30S130P	1300	30	1.75	17.10	TO-247	220
	FGA20S140P	1400	20	1.9	16.57	TO-3P	220

*measured at I_{off} = 40 A, dv/dt =153 V/µs

Fig. 3 compares the E_{off} and $V_{ce(sat)}$ characteristics of a second-generation SA IGBT (FGA20S140P) with those of a first-generation SA IGBT (FGA20S120M) and the best device available from other vendors. All three devices share the 20-A current rating. The $V_{ce(sat)}$ of the FGA20S140P is 1.9 V, which is 0.35 V higher than that of the FGA20S120M (1.55 V) and 0.3 V higher than that of the best competitor (1.6 V). On the other hand, in terms of E_{off}, the second-generation SA IGBT exhibits much lower E_{off} compared to the first-generation device and the best competitor. The E_{off} of the FGA20S140P is 16.57 µJ/A while that of the FGA20S120M is 28.52 µJ/A and that of the best competitor is 20.67 µJ/A.

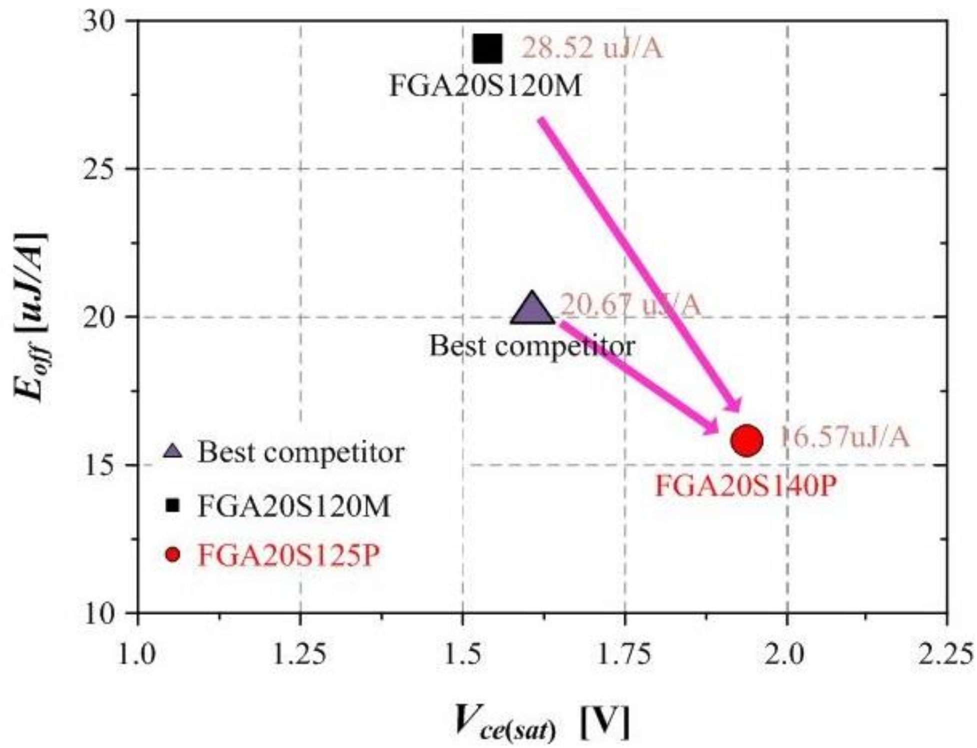

Fig. 3. A comparison of a second-gen SA IGBT (FGA20S140P) with a similarly rated first-gen SA IGBT and the best competitor reveals the tradeoffs in $V_{ce(sat)}$ and E_{off} that these devices present.

Experimental Results

Even though adopting a higher switching frequency in the inverter results in a higher heating efficiency and a cost savings in the IH application, designers have typically not been able to take advantage of this capability. That's because the operating frequency of the IGBT has been limited by the presence of a large tail current, which causes E_{off} to grow as the operating frequency increases. However, due to its smaller tail current characteristics, Fairchild's new SA IGBT allows the IH cooker to be operated at a higher switching frequency than was practical with previous transistors.

To verify the validity of the new SA IGBT in SE-resonant IH applications, an experiment was carried out with a switching test jig. The switching performance, both turn-off and tail-current loss, are compared in Fig. 4. In the experiment, I_{off} and *dv/dt* are 40 A and 153 V/µs, respectively.

In terms of the turn-off instant, the new device (FGA20S140P) shows slightly higher power loss than the previous SA IGBT and the best competitor. The turn-off energy of the FGA20S140P is 229.6 µJ, while that of FGA20S120M is 222 µJ and that of the best competitor is 180 µJ. Nevertheless, the slightly higher loss at turn-off for the new IGBT is outweighed by its much lower tail-current loss.

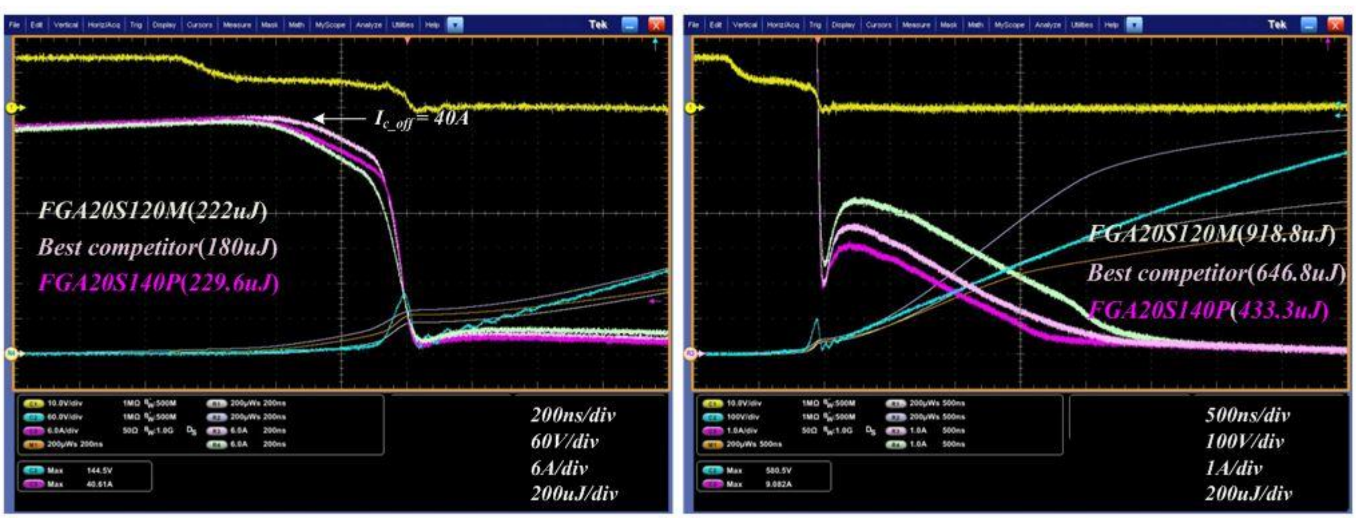

Fig. 4. A comparison of turn-off (left) and tail current (right) characteristics for a second-gen SA IGBT, first-gen SA IGBT and the best competing device reveals that in exchange for slightly higher turn-off loss, the second-gen SA IGBT achieves much lower tail-current loss.

Table 2. Thermal performance comparison for devices tested in Fig 4.

Part Number	BV_{CES} (V)	I_C (A)	Temp. (°C)	
			Model A: 2 kW (f_s @ P_{max} = 21 kHz)	Model B : 2kW (f_s @ P_{max} = 29 kHz)
FGA20S140P	1400	20	83.5	87.1
FGA20S120M	1200	20	87	121.3
Best competitor	1350	20	82	96.9

Conclusion

A latest-generation shorted-anode IGBT that embeds the intrinsic body diode in a fashion similar to that of a MOSFET was introduced and its benefit in the single-ended resonant induction heating applications was described. This device has a higher $V_{ce(sat)}$ when compared to Fairchild's previous version and the best device available from other vendors. However, its tail current is considerably reduced when compared with that of the best competitor as well as that of Fairchild's previous-generation device. For the same current rating, the total

E_{off} of the new device is only 78% that of the best competitor and 57% that of the previous Fairchild device. Consequently, use of the new device becomes more advantageous as the switching frequency gets higher.

About The Author

Jaeeul Yeon serves as a principal application engineer at Fairchild Semiconductor, where he has worked for over six years. A specialist in power electronics, Yeon is now in charge of HV discrete products in consumer power supply systems such as display power supplies, induction cooking inverters, health care systems, etc. Yeon received his Ph. D. degree in electric and electronics engineering from Hanyang University in 2006.

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For further reading on power conversion for induction heating, see the How2Power Design Guide, select the Advanced Search option, go to Search by Design Guide Category and select "Industrial" in the Application category.