Lower Power Loss RC-IGBT for Hybrid Electric Vehicles＊

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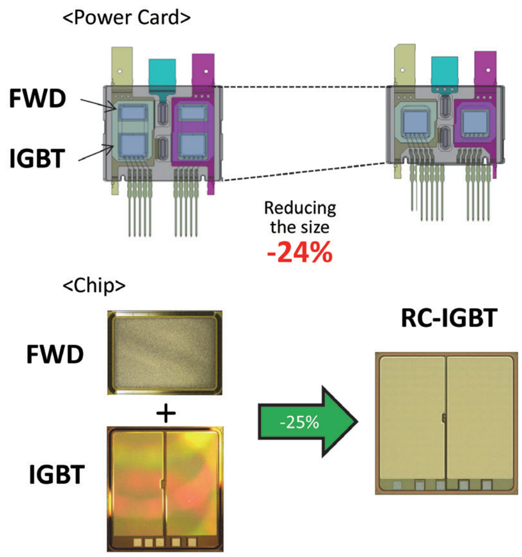
●Short description of the product
This integrated insulated gate bipolar transistor (IGBT) and free wheel diode (FWD) realizes a 25% smaller device chip size and a 13% lower power loss than earlier generation devices for hybrid and electric vehicles (HEVs), while reducing power loss of power control unit (PCU) by 40% compared to earlier-generation HEVs.

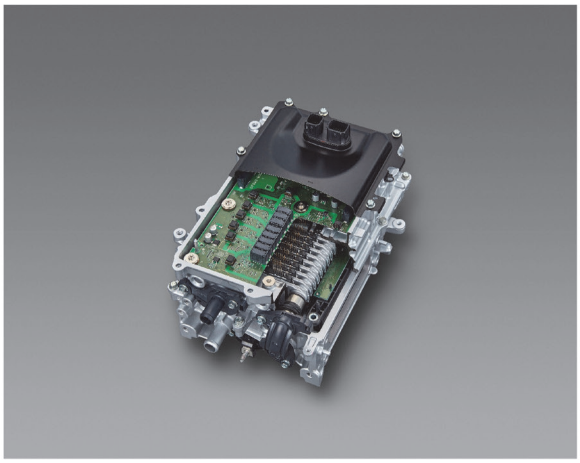
Key words :
RC-IGBT, snap-back phenomenon, Helium irradiation, thinner drift layer

●Photos of the Product



Developed RC-IGBT (right) : Reduction of chip and power card sizes

●Photo #2



Power control unit (PCU)

＊株式会社豊田中央研究所の了承を得て,「The 2020 R&D 100 Awards」提出原稿より一部加筆して転載

What does the product or technology do?

Vehicles are core devices supporting the social and economic foundation of the entire world. On the other hand, vehicle CO_2 emissions and pollution cause environmental difficulties such as global warming. It is crucially important to develop more environmentally conscious vehicles. Hybrid electric vehicles (HEVs), which are driven partly by an electric motor controlled by a power control unit (PCU), are currently increasing in popularity as such type of environmentally conscious vehicle. The PCU consists of power cards, control board, inductors, and capacitors. Our research efforts have led to downsizing the power cards and reducing the power loss of the PCU.

On the power card, an insulated gate bipolar transistor (IGBT) and a free wheel diode (FWD) are placed in parallel. A power device that integrates an IGBT and an FWD is called a reverse conductive (RC) -IGBT (Fig. 1). The RC-IGBT is well known to be effective for device chip and power card size reduction. In fact, RC-IGBTs have been commercialized for home appliances, which require low operating current. Our research efforts have led to the first reported development of an RC-IGBT with operating current of 400 A for use in PCUs of HEVs (Fig. 2).

Our developed RC-IGBT achieves respectively 25% and 24% reductions of the device chip size and power card size. Furthermore, the RC-IGBT achieves a 13% reduction of power loss in IGBT from Toyota's prior generation of HEVs.

As a result, the RC-IGBT contributes to PCU size reduction, thereby facilitating the expansion of HEVs line-up, especially of compact-size HEVs. Furthermore, the RC-IGBT reduces the PCU power loss by 40% compared to prior generation HEVs.

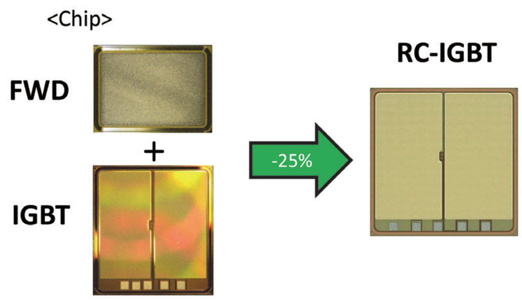


Fig. 1 Developed RC-IGBT (Integrated IGBT and FWD)

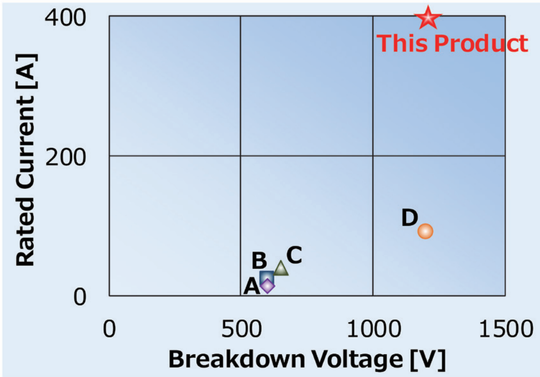


Fig. 2 Rated current–voltage relation between developed product and commercially available RC-IGBT

A: http://www.mitsubishielectric.co.jp/semiconductors/catalog/pdf/powermodule_j_201804.pdf

B: https://www.onsemi.jp/pub/Collateral/ANDNGTB05N60R2DT4GJP-D.PDF

C: https://www.fairchild-semi.com/IGBT_Transistors/NGTB40N65IHRTG_32196.html

D: https://www.infineon.com/cms/jp/product/power/igbt/igbt-discretes/discrete-igbt-with-anti-parallel-diode/650v-1200v-1350v-1600v-next-generation-reverse-conducting-igbt/

(Accessed June 19, 2020)

How does the product operate?

A RC-IGBT has an integrated IGBT and an FWD. In our RC-IGBT, the IGBT regions and the FWD regions are placed alternately (Fig. 3), meaning that the RC-IGBT has adjacent IGBT regions and FWD regions. The boundary region becomes larger for higher current RC-IGBT and induces an unintentional snap-back phenomenon, which causes unstable operation and RC-IGBT power loss.
The RC-IGBT is fabricated using the process flow for an IGBT. That process flow has not been optimized for the FWD. Therefore, the power loss in the FWD region is greater than that in standalone FWD.
Our developed RC-IGBT overcame those two issues of the snap-back phenomenon and the power loss increase in FWD, through optimized arrangement of IGBT and FWD regions and by application of new process techniques as mentioned in following sections.

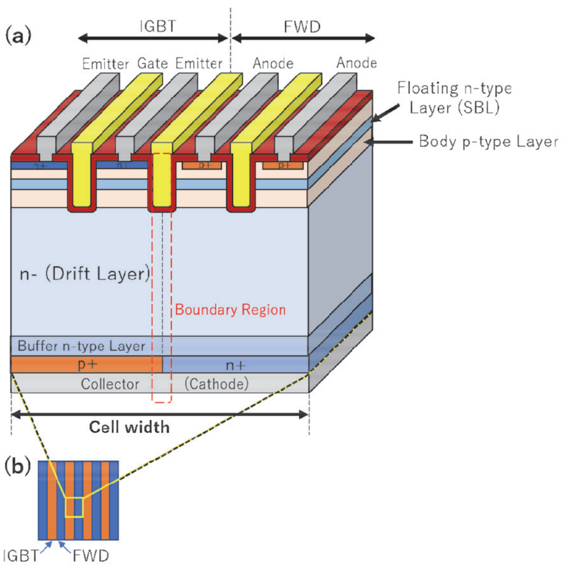


Fig. 3 Schematic illustration of developed RC-IGBT
(a) Perspective view and (b) Plan view from back side

Describe how your product/service improves upon competitive products or technologies

Suppression of snap-back phenomenon

In general, a collector current in an IGBT increases gradually with the increase of the applied collector voltage (Fig. 4). However, in an RC-IGBT, a snap-back phenomenon occurs when the collector voltage increases, which causes unstable operation and power loss in the IGBT region.
The snap-back results from electron injection from the back side of the FWD region to the IGBT region. The snap-back phenomenon therefore occurs in the boundary region between IGBT and FWD regions. To obtain high operating current (i.e. approx. 400 A), the device chip size and the boundary region (as shown in Fig. 3) become larger, making it easy for the snap-back to be induced.
A p-type layer extended to the back side, called deep-p, is formed at the periphery of the device chip to suppress unintentional device breakdown voltage lowering (Fig. 5(a)). The deep-p is connected electrically to the IGBT region, thereby forming a similar boundary of IGBT/FWD. Therefore, the snap-back phenomenon also occurs under the deep-p regions.

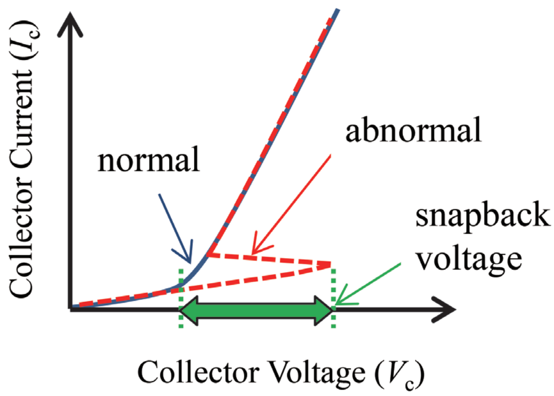
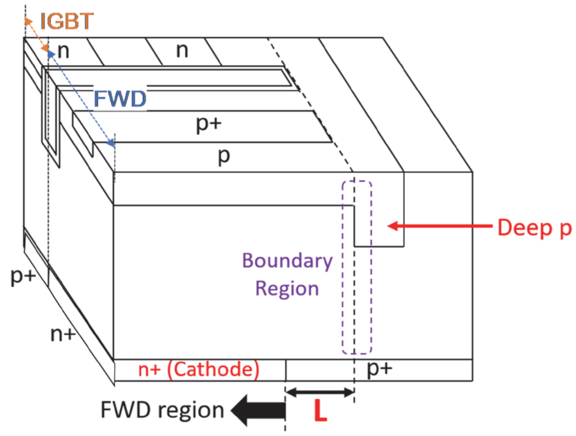
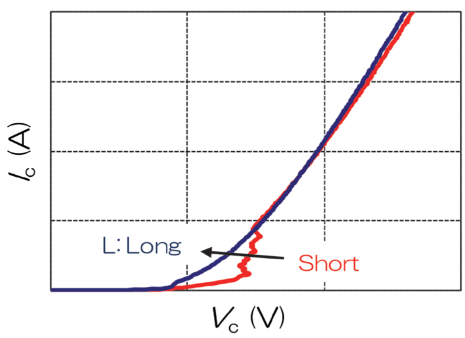


Fig. 4 Schematic illustration of snap-back phenomenon

To suppress the snap-back phenomenon, we reduced the boundary region density in the RC-IGBT (Fig. 6) and optimized the distance between deep-p and FWD regions: L (Fig. 5(a)). Consequently, we suppressed the snap-back in our RC-IGBT (Fig. 5(b)).



(a) Schematic illustration of the RC-IGBT periphery



(b) Current-voltage waveform

Fig. 5 Snap-back phenomenon at RC-IGBT periphery

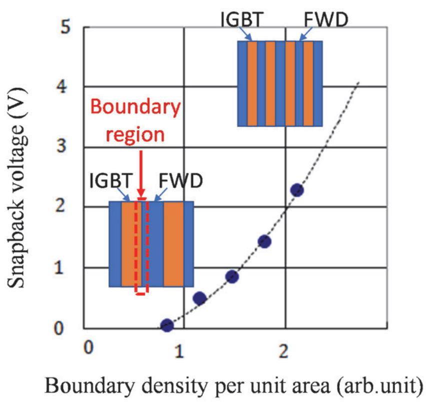


Fig. 6 Boundary dependence number of snap-back voltage

Reduction of power loss in the RC-IGBT

RC-IGBTs are fabricated using a process flow for IGBT. The body p-type layers are formed on the surfaces of the IGBT and the FWD region at the same time to simplify the process flow. The body p-type layer is optimized not for the FWD operation but for the IGBT operation. Therefore, power loss of the FWD region is greater than that of the standalone FWD.

To reduce the power loss of FWD regions, we used Helium irradiation technology for the RC-IGBT. The Helium irradiation forms defects in the “Drift layer” in the RC-IGBT (Fig. 7). The defects accelerate extinguishment of excessive holes in the “Drift layer,” which cause power loss in FWD regions. The Helium irradiation technology reduced power loss in FWD regions by 22%. However, the Helium irradiation technology is not effective in reducing power loss in IGBT region.

Therefore, we introduced thin drift layer technology to reduce the resistance of the drift layer (Fig. 8). The drift layer resistance leads to power loss when current flows through the drift layer. The thinner drift layer engenders low drift layer resistance. The thin drift layer technology reduced power loss by 13% in both IGBT and FWD regions.

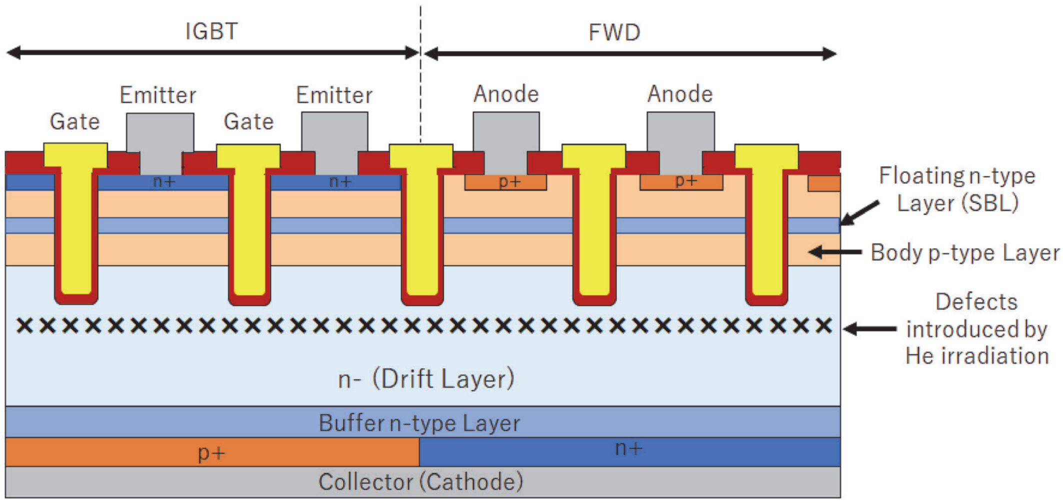


Fig. 7　Defect region formation by Helium irradiation

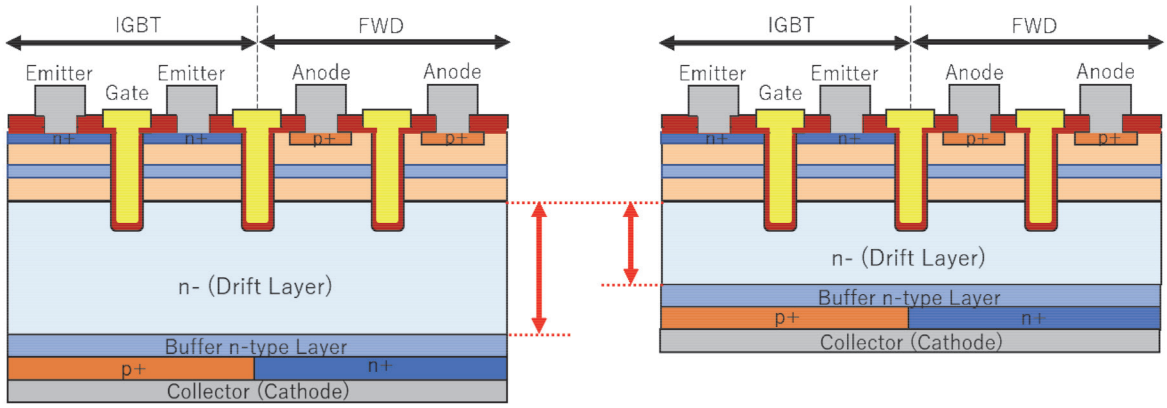


Fig. 8　Thinner drift layer in RC-IGBT to reduce power loss

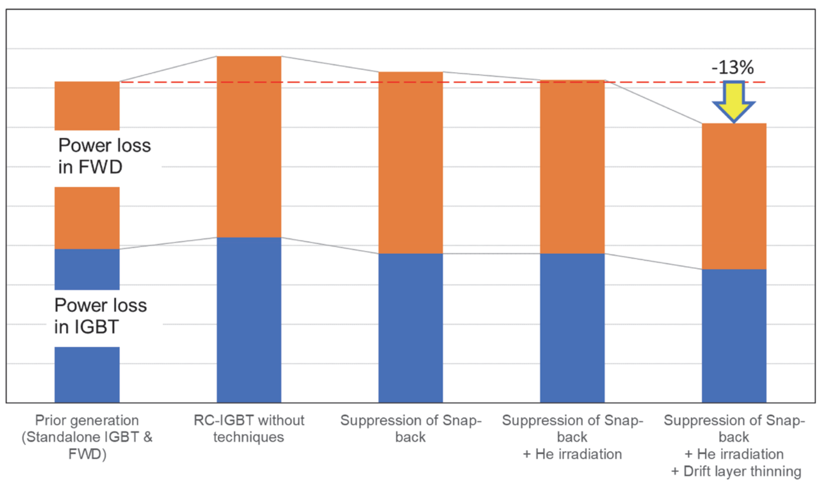


Fig. 9　Reduction of power loss in our RC-IGBT

A summary of the power loss in our RC-IGBT is presented in Fig. 9. The power loss in the IGBT region was reduced mainly through suppression of snap-back phenomenon and thinning of the drift layer. The power loss in the FWD region was reduced mainly by Helium irradiation and thinning of the drift layer. Results show that our RC-IGBT achieved 13% reduction of power loss compared to prior generation devices for HEV PCUs.

If possible, supply a matrix or table showing how the key features of your product compare to existing products or technologies

Fig. 10 and Fig. 11 portray comparisons of steady-state and switching loss, which are power loss components, the trade-off curve shows aspects of the developed product and the prior generation standalone IGBT and FWD. The trade-off curve of IGBT operation in RC-IGBT shows marked improvement. The loss of FWD operation in RC-IGBT can be kept on the trade-off curve of the prior generation FWD.

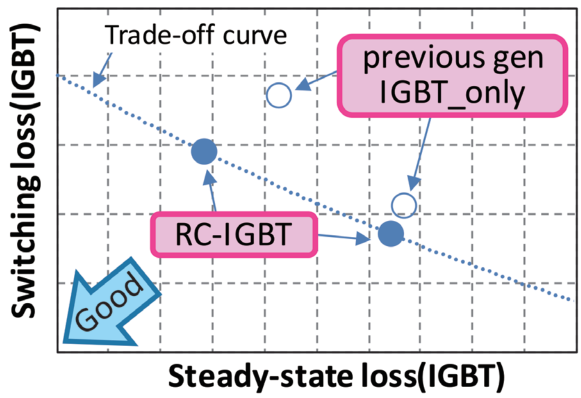


Fig. 10 Steady-state/switching loss trade-off curve for developed product and prior generation standalone IGBT

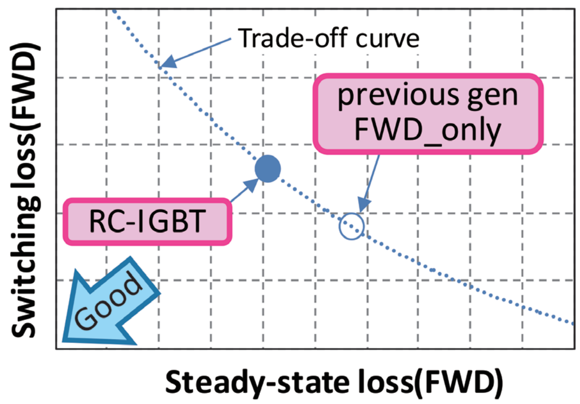


Fig. 11 Steady-state/switching loss trade-off curve for developed product and prior generation standalone FWD

Describe the limitations of your product/service

This product, a power device for HEVs, can switch up to a 1.2 kV breakdown voltage, 400 A operating current, and 10 kHz operating frequency.

Summary of entry

We developed a new RC-IGBT for HEV PCUs. The developed RC-IGBT achieved 25% smaller device chip size compared to prior generation devices. Moreover, 13% reduction of power loss was achieved by snap-back phenomenon suppression, Helium irradiation, and thin drift layer technologies. The developed RC-IGBT reduced 40% power loss of PCU than that of prior generation HEV PCUs. The RC-IGBT contributes to expansion of the HEV line-up, thereby reduction of CO_2 emissions.

Additional supporting documents (optional) #1

Patent List

US	CN	DE
US8716746	CN102376709B	DE102011080891B
US9153575	CN104054179B	DE112013000677T

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