The Advanced Trench HiGT with Separate Floating p-Layer for Easy Controllability and Robustness

Tiger Arai, S. Watanabe*, K. Ishibashi, Y. Toyoda, T. Oda, K. Saito and M. Mori*.
Power & Industrial Systems Division, Power Systems Company, Hitachi, Ltd.
*Hitachi Research Laboratory, Hitachi, Ltd.
Hitachi-shi, Ibaraki-ken, Japan, taiga.arai.ub@hitachi.com

Abstract

In this paper, we propose an advanced trench HiGT (High conductivity IGBT) chip structure and show the new 1700V advanced trench HiGT module characteristics. The concept of the advanced trench HiGT is to allow easier dV/dt control while maintaining low losses and robustness. The feature of the new structure is the deep and separate floating p-layer which has less influence on the trench gate by the floating p-layer through the switching term, so the gate controllability is greatly improved. This new module experimentally shows a 25% reduction in turn-on dV/dt with the same level losses as a conventional trench HiGT. In addition, we confirmed a reduction in turn-off dV/dt, sufficiently wide SOA (Safety Operation Area) and strength against type-3 short-circuits.

1. Introduction

Insulated Gate Bipolar Transistors (IGBTs) are widely used in various inverter systems, such as power supplies and motor drives. With the trend in power electronics demands, IGBTs have been improved. IGBTs have planer MOS gates and trench MOS gates, and the latter are used in miniature processes and are mainly produced with mid-range voltages and high current density.

Fig. 1 shows the different generations of Hitachi's trench IGBT. We firstly developed the trench HiGTs to reduce losses while maintaining robustness[1]. This IGBT has the trench MOS gate arrangement with different intervals and formed the floating p-layers without connecting to the emitter electrode between the trench MOS gates. The MOS channel reduction from this structure reduces the saturation current density Jc(sat) to retain the short-circuit capability. Furthermore, the on-state voltage of this IGBT is lower to reduce power dissipation because the active carriers remain more in the n-drift region.

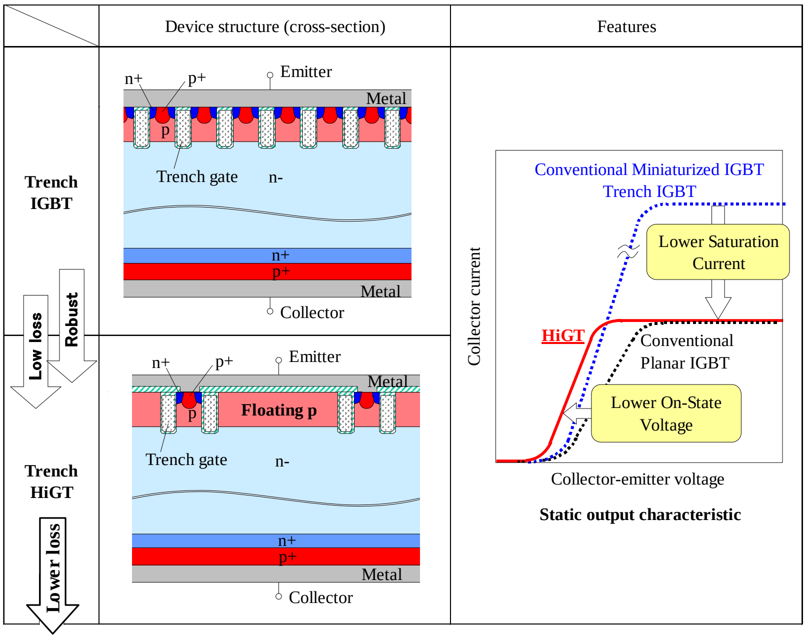


Fig. 1 The different generations of Hitachi's trench IGBT and the advanced trench HiGT

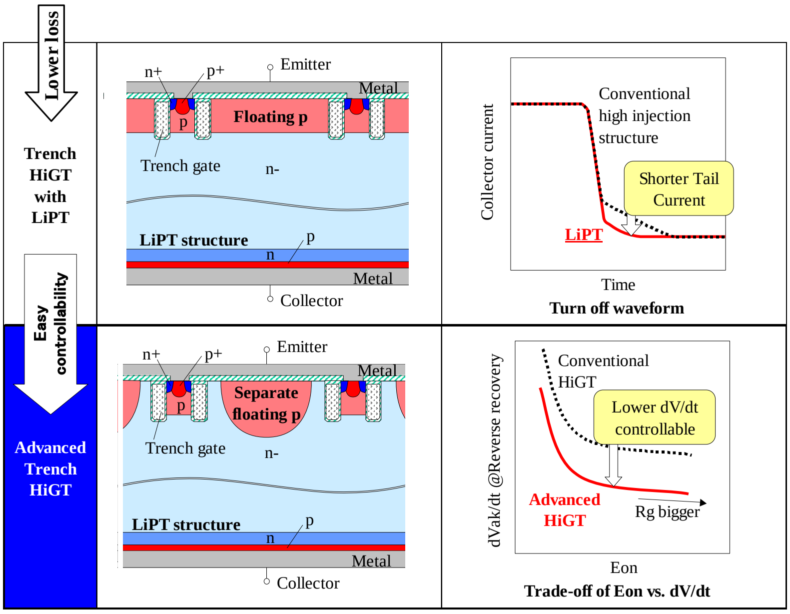


Fig. 1(continued) The different generations of Hitachi's trench IGBT and the advanced trench HiGT

Secondly, we released trench HiGTs with a LiPT (Low injection Punch Through) structure for lower losses[2]. The low hole carrier injection from the p-layer on the collector side shortens the tail current during turn-offs to reduce losses without any conventional lifetime controls.

Currently, easy dV/dt controllability is demanded to reduce losses, EMIs, voltage surges, and other causes of damage to the main circuits. For example high dV/dt causes insulation degradation of the motor coils. Because IGBTs could be used under an upper limit dV/dt condition, it can be useful to design the devices with IGBTs to allow easy dV/dt control over a wide range of conditions with lower losses. Some investigations and countermeasures on this matter have been reported[3][4]. Now we are producing the advanced trench HiGTs which have a new chip structure to realize high dV/dt controllability while maintaining low losses.

2. Device structure

The advanced trench HiGT chip structure is shown in Figs. 1 and 2. The floating p-layer of a conventional trench HiGT is moderately separated from the trench gate to allow easy control of turn-on dV/dt. It is also formed deeper to retain robustness with low losses. Through IGBT switching terms, the floating p-layer voltage fluctuation is caused by the collector voltage change. This directly causes gate uncontrollability especially in the case of the conventional trench HiGT in which the floating p-layer contacts the trench gate. On the other hand, in the case of the advanced trench HiGT, the trench gates are separate from the floating p-layers so that this floating p-layer voltage fluctuation does not affect the

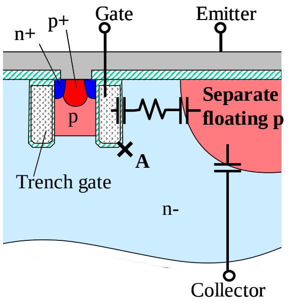


Fig. 2 The advanced trench HiGT structure

gate controllability. Furthermore, the advanced trench HiGT secures low on-state voltages as in the conventional trench HiGTs because of the composition of the floating p-layers. We designed the depth of the floating p-layers and the length between the trench gate and the separate floating p-layer to maintain a high blocking voltage and guard against the damage of the trench gate.

3. dV/dt controllability

We show the measurement data related to the controllability of the advanced trench HiGT's dV/dt for turn-on, reverse recovery, and turn-off.

3.1. Turn-on and reverse recovery

Fig. 3 shows the trade-off between maximum reverse recovery dVak/dt at 25C, Ic=0～150A/chip and Eon at 125C, Ic=150A/chip. (The chip is rated at 150A.) It is experimentally confirmed the advanced trench HiGT offers a better trade-off than a conventional trench HiGT as shown by the simulation results. The advanced trench HiGT provides a 25% reduction in turn-on dV/dt compared to the conventional one with the same level-low losses. Furthermore, the advanced trench HiGT can be controlled down to 13kV/μs, less than the conventional trench HiGT's 19kV/μs. Fig. 4 shows the chip-switching waveforms of the conventional trench HiGT and the advanced trench HiGT. The diode reverse recovery waveform at

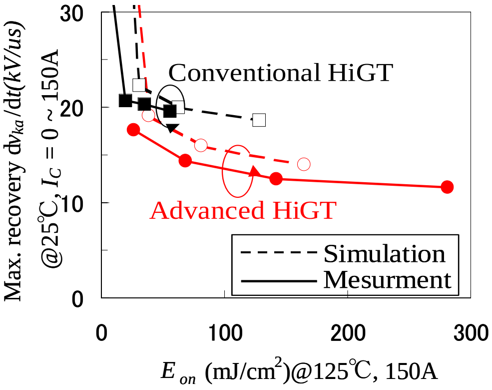


Fig. 3 Trade-off relationship between maximum reverse recovery dVak/dt@25C, Ic=0 ～ 150A/chip and turn-on loss Eon@125C, Ic= 150A/chip. (The chip is rated at 150A.)

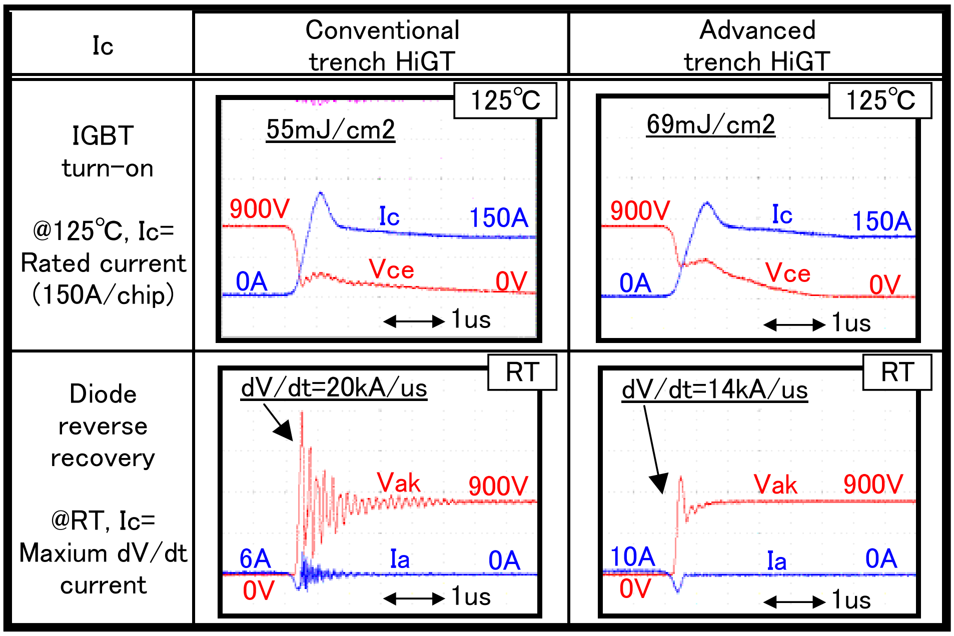


Fig. 4 Chip switching waveforms of the conventional trench HiGT and the advanced trench HiGT

low current with the conventional trench HiGT is a maximum dV/dt of 20kV/μs with voltage ringing, but for the advanced trench HiGT, it is a maximum dV/dt of14kV/μs without voltage ringing.

Fig. 5 shows the advanced trench HiGT's turn-on waveform with various gate resistances at Ic= 150A/chip, 125C. From this result, the advanced trench HiGT is dV/dt controllable between 0.3k and 2.5kV/μs using gate resistance.

From these results we experimentally confirmed that the advanced trench HiGT is easily and widely dV/dt controllable for turn-on and reverse recovery using gate resistance.

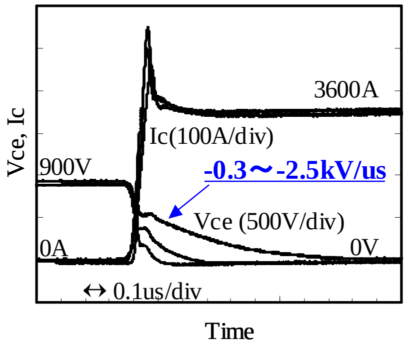
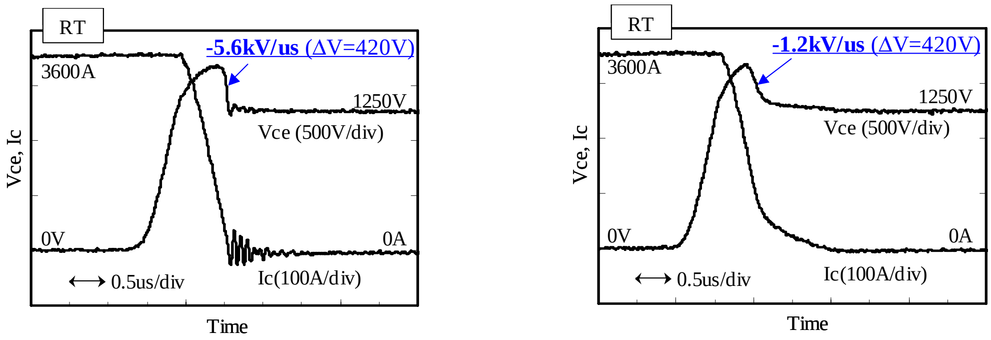


Fig. 5 The turn-on waveforms with various gate resistances for the advanced HiGT @125C, Ic= 150A/chip. (The chip is rated at 150A.)

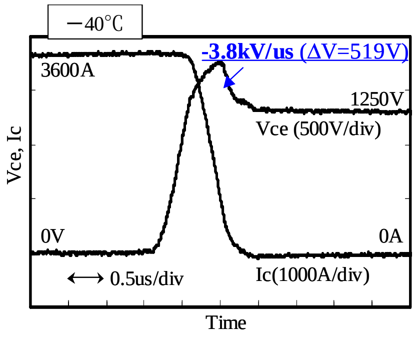
3.2. Turn-off dV/dt controllability

Figs. 6 (a) and (b) show the turn-off waveform of the 1700V, 3600A advanced trench HiGT module at Vcc=1250V, Ic=3600A, RT. We tuned the n-drift layer to 20μm thicker with the simulation results. The tuned module waveform (b) is without voltage ringing. And Fig. 6 (c) shows the turn-off waveform of the advanced trench HiGT measured at –40C. From this result we experimentally confirmed that the tuned module is 3.8kV/μs dV/dt without voltage ringing at –40C.



(a) The conventional trench HiGT module mounted on a 20μm thinner chip, RT

(b) The advanced trench HiGT module, RT



(c) The advanced trench HiGT module, -40C

Fig. 6 Turn-off waveform of the 1700V, 3600A advanced trench HiGT module @Vcc=1250V, Ic=3600A, Ls=55nH, Vge=15V/-15V, Rg(off)=1.5Ω.

Fig. 7 shows the turn-off dV/dt vs. Ic of the 1700V, 3600A advanced trench HiGT module at Vcc=1250V, RT. The advanced trench HiGT with tuned thickness has the desirable trait of lower turn-off dV/dt than the conventional trench HiGT with pre-tuned thickness over the full measured collector current range.

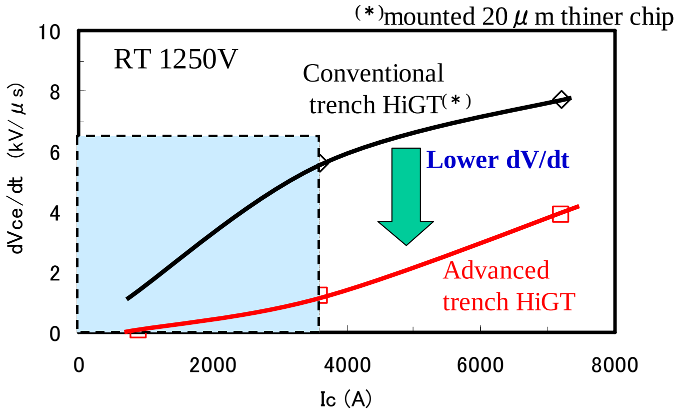
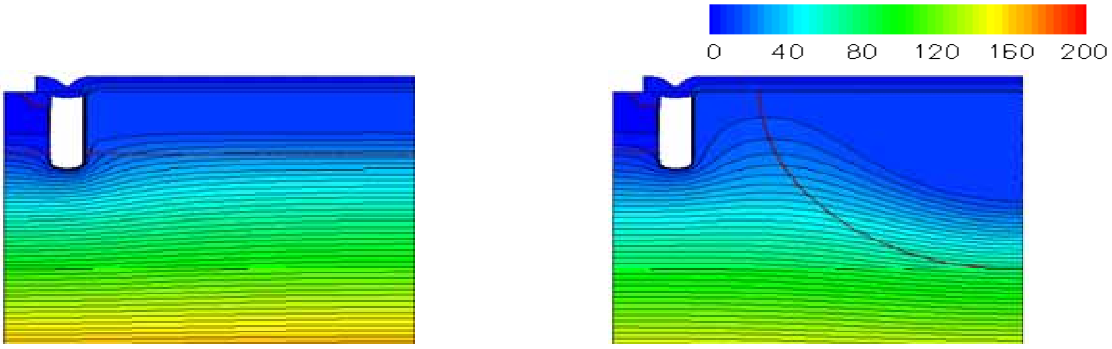


Fig. 7 Turn-off dV/dt vs. Ic of the 1700, /3600A advanced trench HiGT module @Vcc=1250V, Ic=3600A, Ls=55nH, Vge=15V/-15V, Rg(off)=1.5Ω, RT

4. Robustness

This new structure needs to consider the blocking damage around the trench gate. Fig. 8 shows the simulation results of the potential distribution around the trench gate on DC blocking. From the results of the device simulation, the trench bottom (point A in Fig. 2) is the avalanche point. Firstly, the deeper floating p-layer is effective in reducing the electric field at the trench bottom. Secondly, we designed the width between the trench gate and the separate floating p-layer. Fig. 9 shows the simulation result of the relationship between the static avalanche voltage and the unit cell size of IGBT. The relationship between the unit cell size of IGBT and the width between the trench gate and floating p-layer is linear. From this simulation result, it appears that the advanced trench HiGT can be designed with a higher avalanche voltage than the conventional trench HiGT. We experimentally confirmed that the advanced trench HiGT module cleared both the collector - emitter DC blocking test and the gate - emitter DC blocking test.



(a) Conventional trench HiGT

(b) Advanced trench HiGT

Fig. 8 Potential distribution around a trench gate on DC blocking (Simulation) @Vce=1700V, Vge=0V, 25C

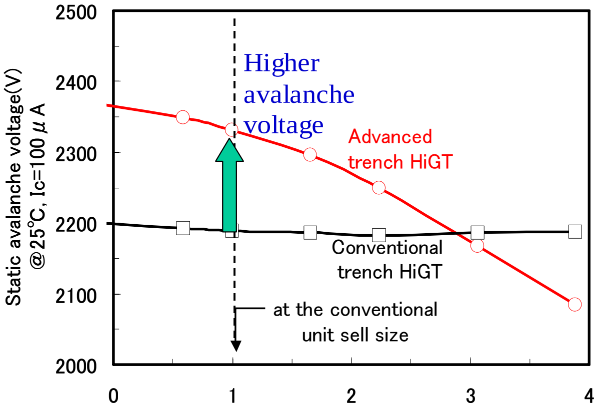
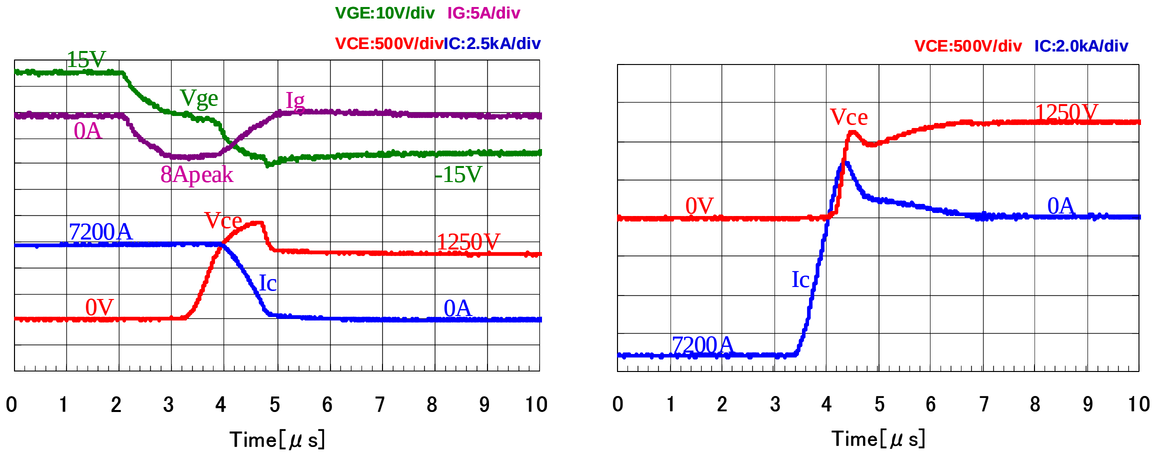


Fig. 9 Static avalanche voltage vs. the unit cell size of IGBT (Simulation)

Fig. 10(a) shows the high-current turn-off waveform of the 1700V, 3600A advanced trench HiGT module. Fig. 10(b) shows the high-current reverse-recovery waveform of the 1700V, 3600A advanced trench HiGT module. We experimentally confirmed that the RBSOA and recovery SOA of the advanced trench HiGT module are large enough.



(a)turn-off

(b)reverse-recovery

Fig. 10 High-current switching waveform of the 1700V/3600A advanced trench HiGT module @ Vcc= 1250V, Ic=7200A, Ls=55nH, Vge=15V/-15V, Rg(on)=3.3W, Rg(off)=1.5W, 150C

Fig. 11 shows the type-3 short-circuit mode waveform of the 1700V, 3600A advanced trench HiGT module. In a type-3 short-circuit, while the main current flows back through a free-wheel-diode in a two-level-inverter circuit with inductances as load, the other arm's IGBT breaks down and the circuit shorts between the upper and lower arms. We experimentally confirmed that the advanced trench HiGT module turns off safely after 10μs of a type-3 short-circuit.

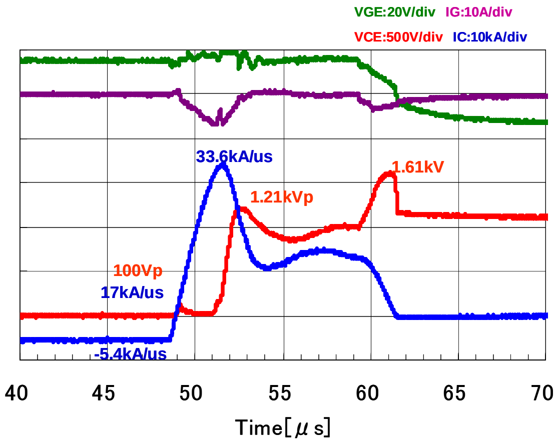


Fig. 11 type-3 short-circuit mode waveform of the 1700V/3600A advanced trench HiGT module @Vcc=1150V, Ic=5400A, Ls=55nH, Vge=15V/-15V, Rg(on/off)=3.3W/1.5Ω, 150C

5.Losses

Fig. 12 shows the trade-off relationship between Eoff and Vce(sat). The advanced trench HiGT has the same low level of losses as the conventional trench HiGT. This is because the advanced trench HiGT has the same structure for the floating p-layer as the conventional trench HiGT, and the active carrier density of the n-drift layer could be as high as the conventional one.

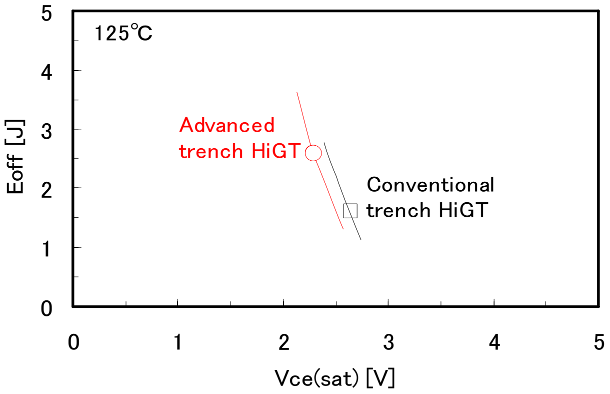


Fig. 12 trade-off relationship between Eoff and Vce(sat)

6. Conclusion

We proposed a chip structure for an advanced trench HiGT with a deep, separate floating p-layer and showed the characteristics of the new 1700V, 3600A advanced trench HiGT module. Experimentally, this new module showed 25% reduction in turn-on dV/dt with the same low level of losses as the conventional module and ringing free turn-off waveform over the full collector current range (0 - 3600A) from -40 to 150C. In addition, we confirmed that the SOA is wide enough and the strength against type-3 short-circuits is sufficient. Because of these features, this new module can be driven easily and used at the lowest loss conditions.

Reference

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