A Snapback-Free Reverse-Conducting LIGBT with P floating region at Collector

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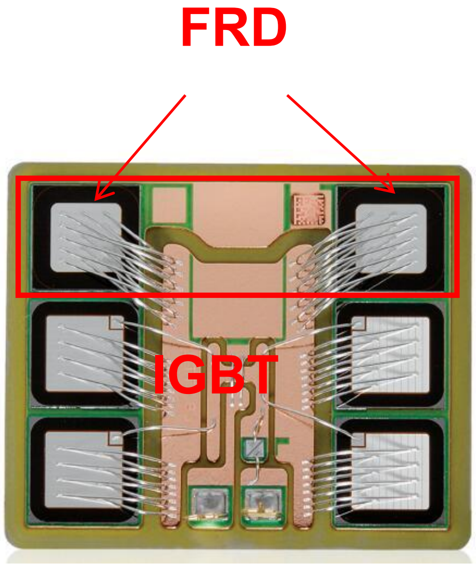
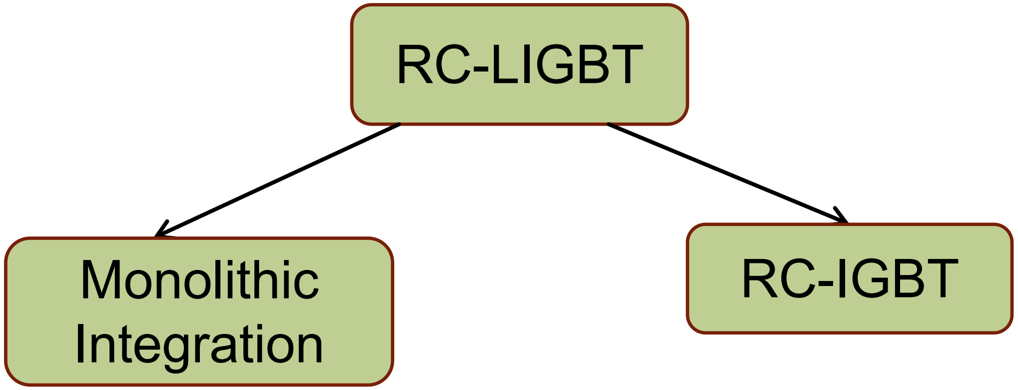
1.Introduction



IGBT power module

Large volume, high parasitic resistance and inductance



RC-LIGBT

Monolithic Integration

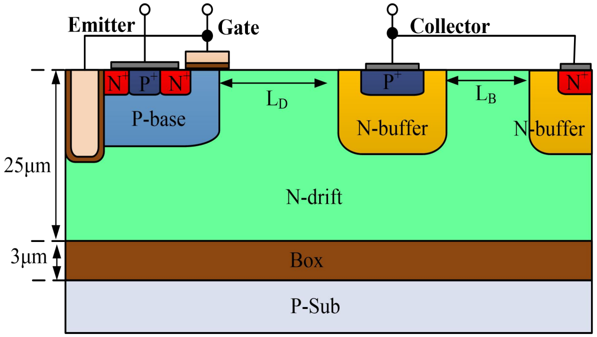
RC-IGBT

- Miniaturization and integration
- Enhanced anti-interference ability
- SOI - achieving complete isolation of high and low voltage parts

- Reverse conduction
- Better V_{on}-E_{off} compromise

Disadvantage:
Snapback phenomenon during forward conduction

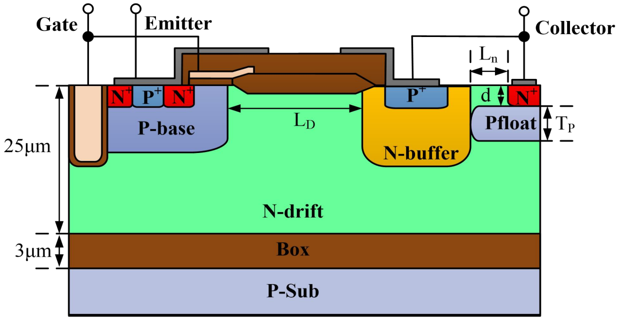
2.Device Structure and Principle



Separated-Shorted-Anode LIGBT，SSA-LIGBT

inhibits the snapback phenomenon by increasing the distance between the p^+ collector and n^+ short circuit area

Disadvantage：cause the chip area to increase



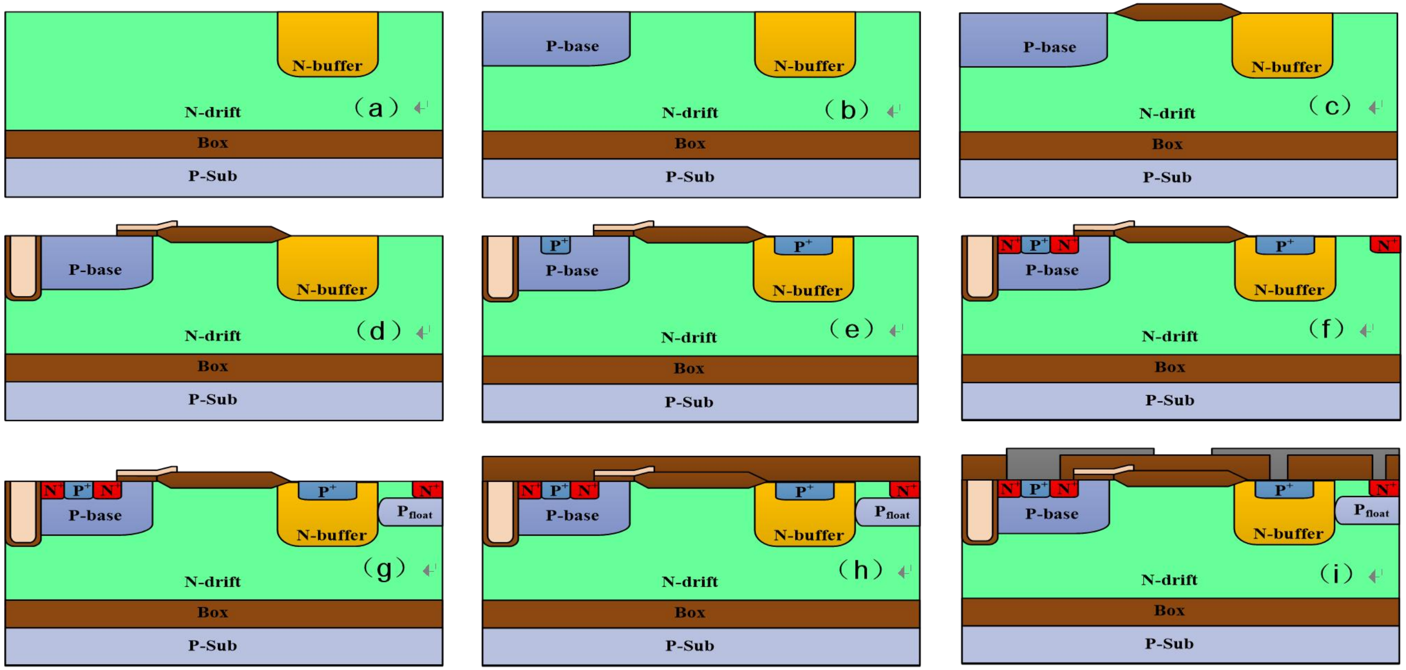
trench-planar gate RC-LIGBT

introducing a P floating zone below the n^+ short region on the collector side

In the early stage of forward conduction, the p floating region can hinder the flow of electrons to the n^+ short region, and can suppress or even eliminate the snapback phenomenon at a smaller cell size.

2.Device Structure and Principle

The key process steps of making trench-planar gate RC-LIGBT



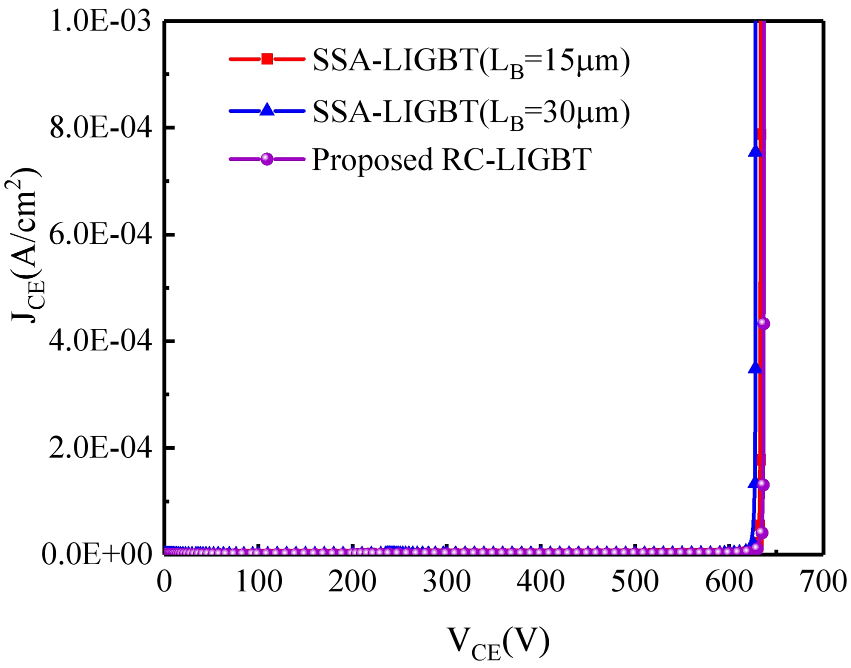
(a) Phosphorus ion implantation to form N-buffer zone. (b) boron ion implantation to form P-base zone. (c) thermal oxidation to form field oxide layer. (d) etching groove, dry oxygen growth gate oxide layer, chemical vapor deposition of polysilicon film, photolimetric polysilicon gate. (e) Boron ion implantation to form p^+ ohmic contact zone and p^+ collector zone. (f) photolithography n^+ emission zone and n^+ short circuit zone, phosphorus ion implantation. (g) photolithography P_{float} zone, boron ion Retro Grade Doping process, high temperature promotion to form P_{float} zone with n^+ emission zone and n^+ short circuit zone. (h)phospho-silicate glass, PSG deposition (i) contact hole etching and metallization

2.Device Structure and Principle

Main structural parameters

parameter	SSA-LIGBT	Proposed RC-LIGBT
SOI layer thickness (μm)	25	25
Box thickness (μm)	3	3
Gate Oxide thickness (nm)	100	100
Distance between two N-buffer zones, L_B (μm)	15/30	/
Cell size (μm)	88/103	71
P_{float} region doping concentration, N_p (cm-3)	/	1×10^{16}
P_{float} region thickness, T_p(μm)	/	1
P_{float} region depth, d (μm)	/	0.5
length of the N-drift region above the P_{float} region, L_n(μm)	/	1.5

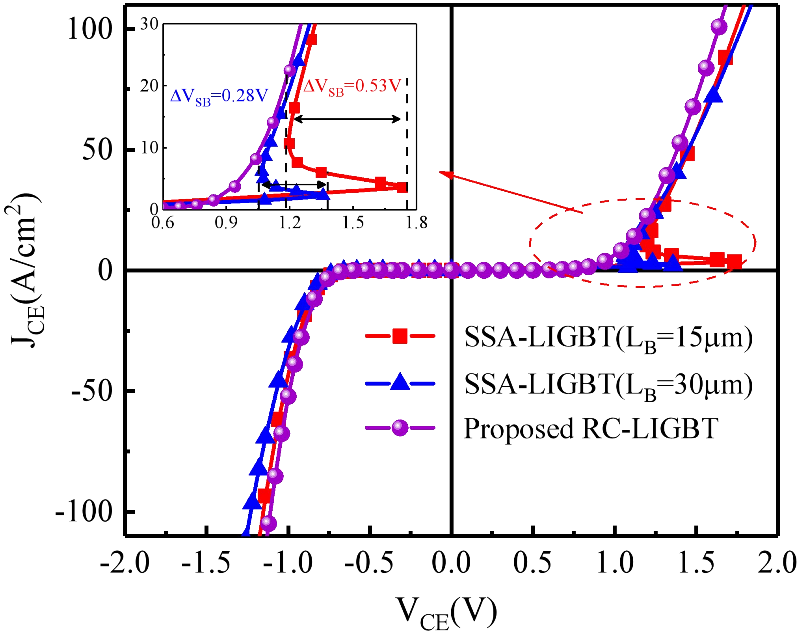
3.Discussion-Blocking characteristics



The breakdown voltage of the proposed RC-LIGBT is 637 V

Blocking characteristics of different LIGBTs

3.Discussion-Output characteristics

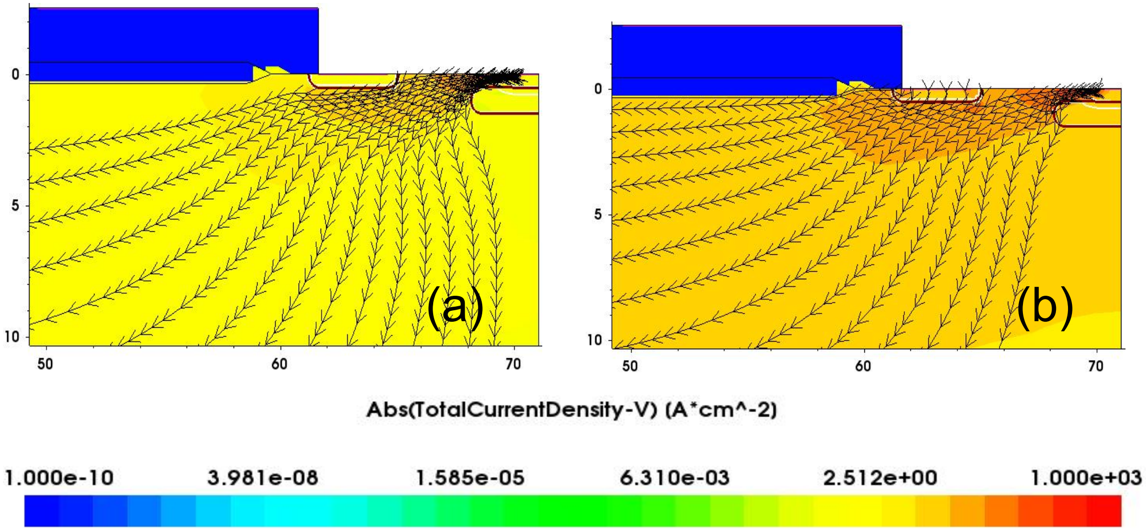


Output characteristics of different LIGBTs

parameter	SSA-LIGBT（L_B=15μm）	SSA-LIGBT（LB=30μm）	Proposed RC-LIGBT
cell size（μm）	88	103	71
ΔV_{SB}（V）	0.53	0.29	0
V_{on}（V）	1.74	1.78	1.63
$V_{r\text{-}on}$（V）	1.15	1.23	1.1

The proposed RC-LIGBT completely eliminates the snapback phenomenon and has a lower forward and reverse conduction voltage drop

3.Discussion-Snapback phenomenon inhibition mechanism

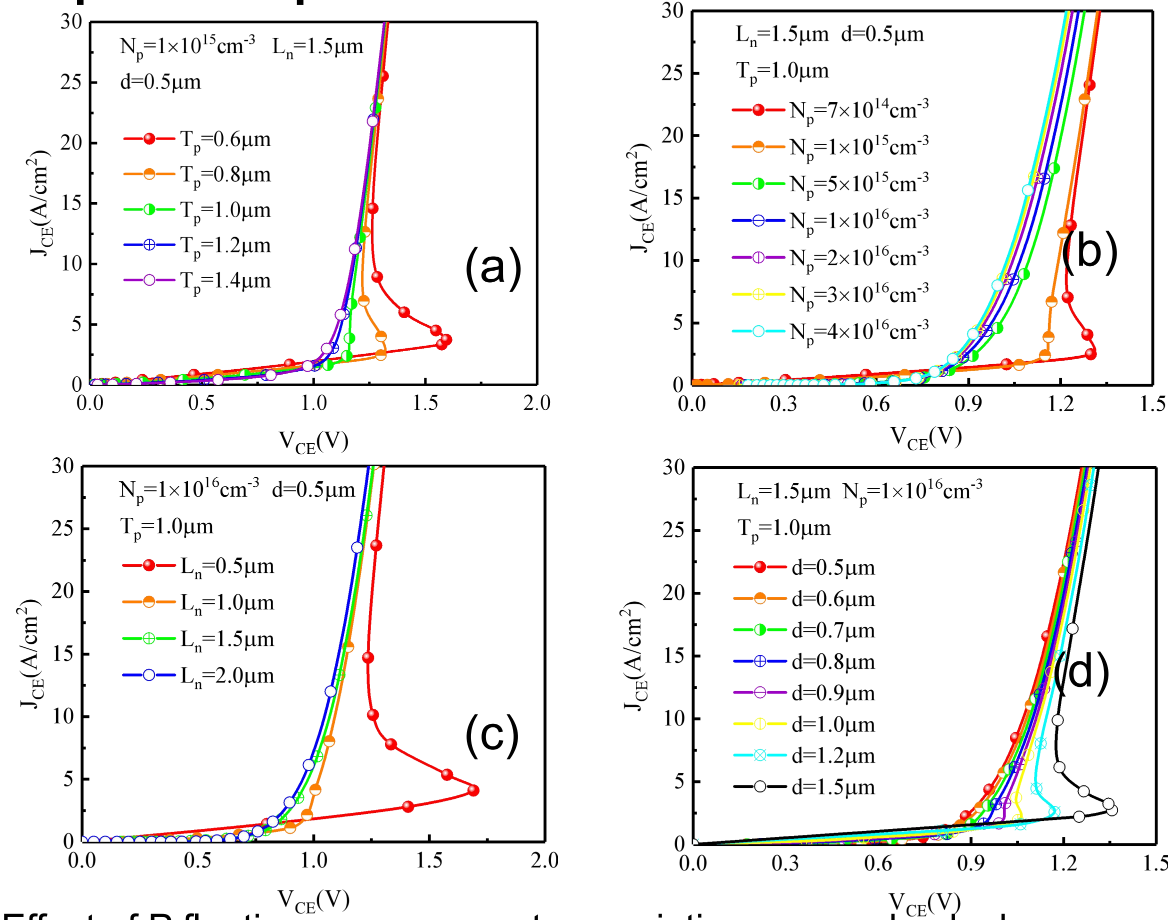


Collector side current distribution under different voltages of the proposed RC-LIGBT forward conduction.(a)V_{CE}=0.7V. (b)V_{CE}=0.9V

The P floating zone can block the flow of electrons to the n^+ short zone, promoting the early opening of the p^+/N-buffer junction

Complete the conversion of single and bipolar modes at V_{CE}=0.9V, eliminating snapback phenomenon

3.Discussion-The influence of parameters on snapback phenomenon

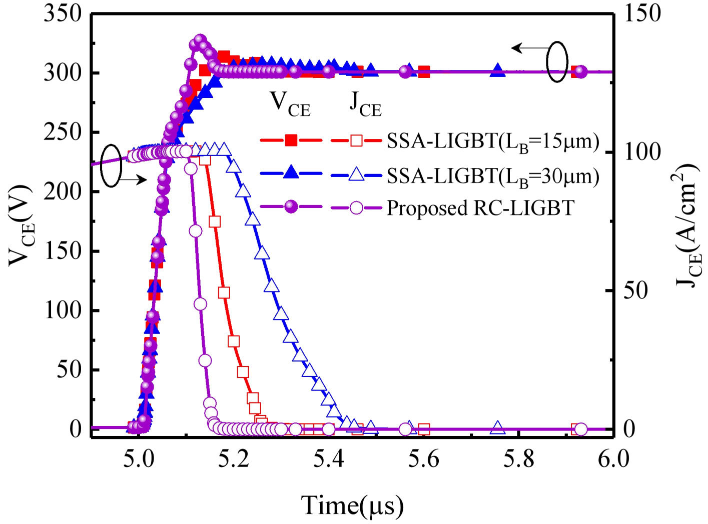


The larger T_p, N_p, and L_n, the less obvious the Snapback phenomenon;

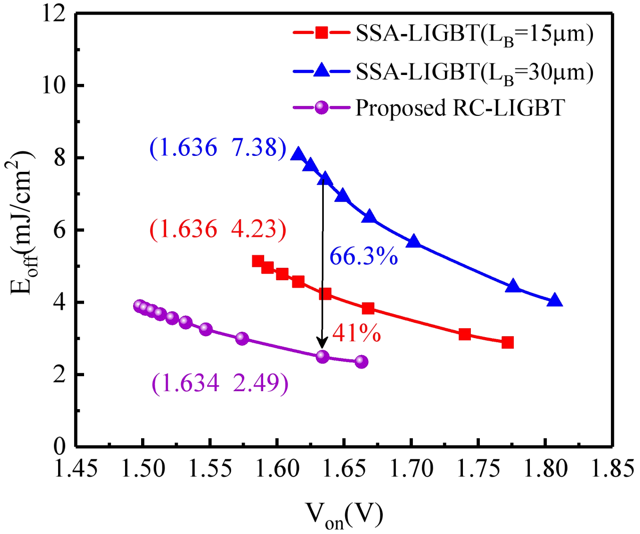
The larger the d, the more obvious the Snapback phenomenon

Effect of P floating zone parameters variation on snapback phenomenon (a) P floating zone thickness, T_p, (b) P floating zone doping concentration, N_p, (c) length of the N-drift region above the P_{float} region, L_n, (d) thickness of the N-drift region above the P_{float} region, d,

3.Discussion-turn-off characteristic



turn-off characteristic curves of different LIGBTs (V_{on}=1.63V, J_{CE}=100A/cm²)

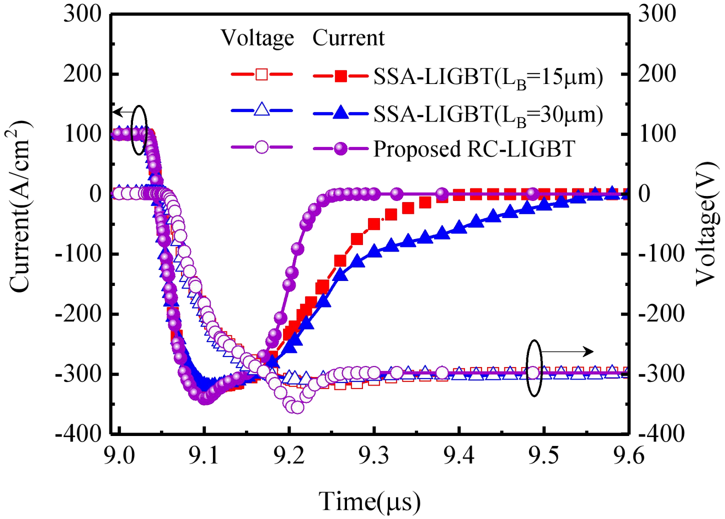


trade-off curves between E_{off} and V_{on} of the different LIGBTs (V_{on}=1.63V, J_{CE}=100A/cm²)

parameter	SSA-LIGBT（L_B=15μm）	SSA-LIGBT（L_B=30μm）	Proposed RC-LIGBT
ΔV_{SB}(V)	0.53	0.29	0
t_d(off)(ns)	153	216	120
t_f(ns)	95	191	40
E_{off}(mJ/cm2)	7.38	4.23	2.49

Proposed RC-LIGBT has better turn-off characteristics and better V_{on}-E_{off} compromise

3.Discussion-reverse recovery characteristic



reverse recovery characteristic curves of integrated diodes in above different RC-LIGBTs

parameter	SSA-LIGBT（L_B=15μm）	SSA-LIGBT（L_B=30μm）	Proposed RC-LIGBT
$V_{r\text{-}on}$（V）	1.15	1.23	1.1
J_{RM}（A/cm²）	327	319	340
t_{rr}（ns）	293	428	196
Q_{rr}（μC/cm²）	57.6	66.5	43.5

Compared with SSA-LIGBT with L_B of 15 μm and 30 μm respectively, the reverse recovery peak current density,J_{RM} of the proposed RC-LIGBT is slightly higher, and the reverse recovery time,t_{rr} decreases by 33% and 54%., The reverse recovery charge,Q_{rr} decreased by 24.5% and 34.6%, respectively.

4.Conclusion

parameter	**SSA-LIGBT（L_B=15μm）**	**SSA-LIGBT（L_B=30μm）**	**Proposed RC-LIGBT**
cell size（μm）	88	103	71
ΔV_{SB}（V）	0.53	0.29	0
V_{on}（V）	1.74	1.78	1.63
$V_{r\text{-}on}$（V）	1.15	1.23	1.11

Compared with the traditional SSA-LIGBT with L_B of 15 μm and 30 μm, the proposed RC-LIGBT completely eliminates the snapback phenomenon;

under the same V_{on}, the E_{off} of the proposed RC-LIGBT decreased by 41% and 66.3%, and the Q_{rr} decreased by 24.5% and 34.6%, respectively.

Thank you