

P-Channel Power MOSFETs for Space Applications

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ABSTRACT

Fuji Electric has added a family of p-channel power MOSFETs to its lineup of power MOSFETs for space applications. Depending on the application, designers can now choose between the existing n-channel power MOSFETs and the new chips, allowing them to reduce the system part count and achieve higher system reliability. Like the n-channel power MOSFETs, the new chips use quasi-plane junction technology to lower the resistance of the drift layer, thus lowering the on-resistance. A low-temperature process is used to form gate oxide films in all diffusion layers, achieving high total ionizing dose (TID) tolerance.

1. Introduction

That the benefits of utilizing outer space for such applications as communication satellites, meteorological satellites, GPS and earth observation have permeated our daily lives is well-known. The electronic devices and switching power supplies installed in artificial satellites are required to be highly efficient so as to efficiently utilize limited power in outer space and to have a reduced number of components so as to ensure system reliability. Moreover, the power metal-oxide-semiconductor field-effect-transistor (MOSFET), a key device for power conversion, is required to be a low loss device as well as to have high reliability against ionizing radiation⁽¹⁾ and to be resistant to high-energy charged particles (heavy particles)⁽²⁾ and the like in a space environment.

Fuji Electric has previously developed and commercialized n-channel high-reliability power MOSFETs for space applications⁽³⁾. Recently, p-channel power MOSFETs for space applications have been newly added to Fuji Electric's product lineup. Compared to the n-channel power MOSFET, the p-channel power MOSFET has on-resistance that is 2 to 3 times larger in principle, and this is a disadvantage, but because its polarity is reversed, high-side switches and other circuits can be configured more simply. For this reason, the p-channel power MOSFET has the advantage of allowing the number of components to be decreased, thereby enhancing reliability and enabling a reduction in the size and weight of the overall system. Based on the technology cultivated with n-channel power MOSFET for space applications, Fuji Electric has developed and commercialized p-channel MOSFETs for space applications. The features and

technology of these products are introduced below.

2. Product Features

Table 1 lists Fuji Electric's product lineup of p-channel power MOSFETs, and Table 2 shows the differences in requirements for power MOSFETs for consumer-use and power MOSFETs for space applications. The MOSFETs for space applications maintain the equivalent low on-resistance of consumer power MOSFETs while providing the capability to tolerate a space environment.

2.1 Tolerance to ionizing radiation (TID tolerance)

Ionizing radiation is present in the environment along the orbit of an artificial satellite or the like. Generally, if a power MOSFET normally used at ground level is used in an environment of ionizing radiation, the breakdown voltage will decrease and the gate threshold voltage V_{th} that controls the on-off control of the power MOSFET will shift. The marketplace requirement for ionizing radiation tolerance is 1,000 Gy, which is the equivalent exposure as 10 years of geostationary orbit, and the ability to tolerate this level of exposure is ensured with the newly developed p-channel power MOSFET. Ionizing radiation tolerance is assessed by evaluating the change in characteristics that occurs when a product is actually irradiated with ionizing radiation. Figure 1 shows the evaluation results of breakdown voltage BV_{DSS} and V_{th} , which are particularly susceptible to ionizing radiation. BV_{DSS} does not change at all. Also, the shift in V_{th} is limited to within the range of the specification.

2.2 Heavy particle tolerance (SEE tolerance)

In space, heavy particles emitted from solar winds, supernova explosions and the like fly back and forth.

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Table 1 Product list

Product type	V_{DS} (V)	I_D (A)	I_D (Pulse) (A)	$R_{DS(on)}$ max. *1 (Ω)	P_D *2 (W)	V_{GS} (V)	$V_{GS(th)}$ (V)	Q_g max. (nC)	Radiation level (krad)	SEE *3 LET MeV/ (mg/cm ²)	Package type	Mass (g)
JAXA R 2SJ1 A01	-100	-42	-168	0.045	250	± 20	-2.5 to -4.5	230	100	37	TO-254	9.3
JAXA R 2SJ1 A02	-100	-25	-100	0.097	125	± 20	-2.5 to -4.5	95	100	37	TO-254	9.3
JAXA R 2SJ1 A03	-100	-11	-44	0.226	62.5	± 20	-2.5 to -4.5	40	100	37	TO-254	9.3
JAXA R 2SJ1 A04	-100	-42	-168	0.038	250	± 20	-2.5 to -4.5	230	100	37	SMD-2	3.3
JAXA R 2SJ1 A05	-100	-29	-116	0.09	150	± 20	-2.5 to -4.5	95	100	37	SMD-1	2.6
JAXA R 2SJ1 A06	-100	-13	-52	0.219	70	± 20	-2.5 to -4.5	40	100	37	SMD-0.5	1.0
JAXA R 2SJ1 A07	-200	-35	-140	0.091	250	± 20	-2.5 to -4.5	230	100	37	TO-254	9.3
JAXA R 2SJ1 A08	-200	-16	-64	0.21	125	± 20	-2.5 to -4.5	95	100	37	TO-254	9.3
JAXA R 2SJ1 A09	-200	-7.5	-30	0.487	62.5	± 20	-2.5 to -4.5	40	100	37	TO-254	9.3
JAXA R 2SJ1 A10	-200	-37	-148	0.084	250	± 20	-2.5 to -4.5	230	100	37	SMD-2	3.3
JAXA R 2SJ1 A11	-200	-18	-72	0.203	150	± 20	-2.5 to -4.5	95	100	37	SMD-1	2.6
JAXA R 2SJ1 A12	-200	-8.5	-34	0.48	70	± 20	-2.5 to -4.5	40	100	37	SMD-0.5	1.0

*1 : $R_{DS(on)}$: $V_{GS} = -12$ V,*2 : P_D : $T_C = 250^\circ\text{C}$ *3 : SEE: Kr, Energy: 520 MeV, Range: 63 μm , $V_{DS} = \text{rated } V_{DS}$, $V_{GS} = +5$ V

Table 2 Requirements of power MOSFET for space applications

Requirements		Consumer-use MOSFET	Space-use MOSFET
Ionizing radiation tolerance (TID tolerance)		×	◎
Heavy particle tolerance (SEE tolerance)		×	◎
Long-term reliability		○	◎
Electrical characteristics	Breakdown voltage	200 V	200 V
	On-resistance	◎	◎

TID : Total ionizing dose

SEE : Single event effect

◎: Fully meets requirements

○: Meets requirements

×: Does not meet requirements

The phenomenon in which a single incident heavy particle can cause degraded characteristics or permanent damage in a biased MOSFET is generically referred to as a “single event effect” (SEE). The probability of impact in space by a heavy particle with a larger mass is

lower, but such a particle would have a large amount of energy and would have a significant effect on a MOSFET. The magnitude of the energy that a heavy particle would transfer to a MOSFET is described by the linear energy transfer (LET) of the particle. Additionally, the SEE tolerance also depends on the biased state of the power MOSFET at the time when the heavy particle comes in, and the higher the V_{DS} and V_{GS} , the greater the susceptibility to damage.

Therefore, the SEE tolerance is generally expressed with the magnitude of the LET and the useable areas of V_{DS} and V_{GS} . Figure 2 is shown for the power MOSFET at a LET value of 37 MeV/(mg/cm²). Because a reverse bias of +5 V or greater is not used with V_{GS} , in the actual useable area, the tolerance extends to the rated value of V_{DS} . The probability that a heavy particle having this LET value would collide with the MOSFET corresponds to approximately once every 200 years (estimated assuming an orbit altitude of 550 km and an orbital inclination angle of 31°), and

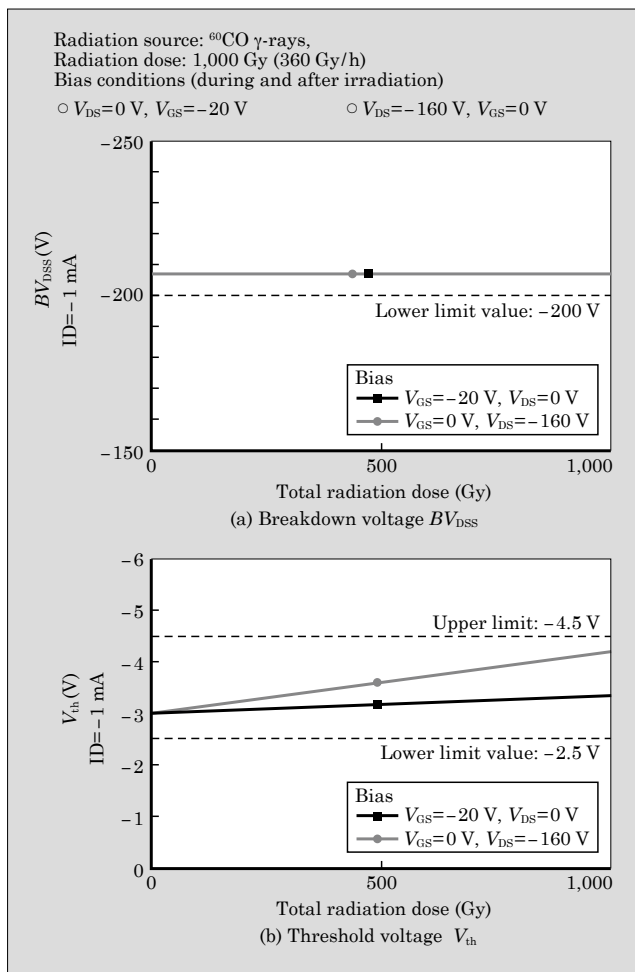


Fig.1 Tolerance to ionizing radiation (TID tolerance)

extremely high reliability against heavy particles is provided.

2.3 Long-term reliability

A metallic hermetically sealed package is used to ensure long-term reliability of the package. In order to improve thermal cycle tolerance, the package frame (part into which the MOSFET chip is mounted) is made from CuW (copper tungsten), which has a coefficient of thermal expansion extremely close to that of silicon (the material from which the MOSFET chip is made). Additionally, the hermetically sealed package is made hollow (Fig. 3) and filled with dry nitrogen to protect the power MOSFET chip from exogenous degradation modes.

3. Technology Applied to the MOSFETs for Space Applications

The technology developed for the previously commercialized 2nd generation n-channel power MOSFETs for space applications was also applied to these p-channel MOSFETs. This section introduces the technology for ensuring TID tolerance and low on-resistance.

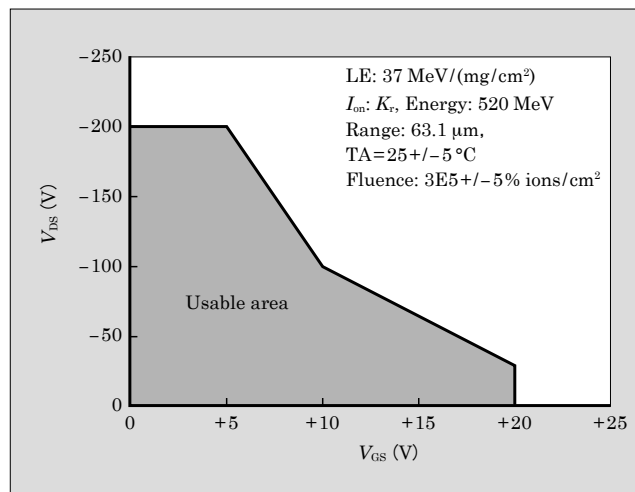


Fig.2 Tolerance to heavy particles (SEE tolerance)

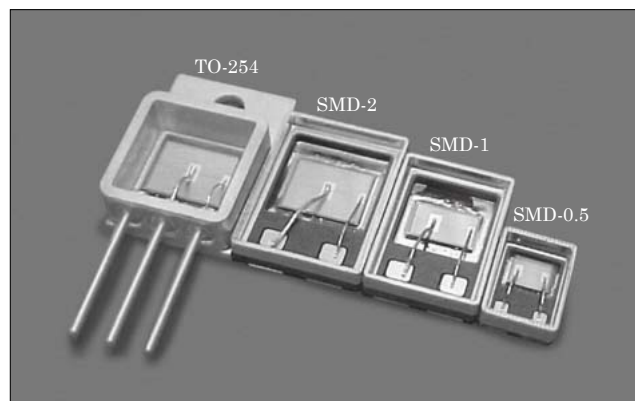


Fig.3 Internal structure of power MOSFETs for space applications

3.1 Application of low-temperature process

The phenomenon of a V_{th} shift is caused by electrical charge becoming trapped in the oxide film as a result of ionizing radiation.

When a MOSFET is exposed to ionizing radiation, electrons and holes are induced in its oxide film. The holes, in particular, become trapped in the oxide film and form a fixed positive electrical charge that appears in the electrical characteristics as a shift in V_{th} .

From prior research, it is known that the greater the thermal history of exposure to high-temperatures, the greater amount of charge that will be trapped in an oxide film. In a consumer-use MOSFET, an efficient manufacturing process and stable electrical characteristics can be provided through the use of a gate electrode (on which a gate oxide film has also been formed) as a self-aligned mask. With this process, however, the gate oxide film acquires a thermal history of high-temperature exposure during the diffusion layer fabrication process, and the oxide layer ends up trapping a large amount of charge.

Therefore, a process flow in which the gate oxide film is formed after fabrication of the entire diffusion layer was applied to MOSFETs for space applications

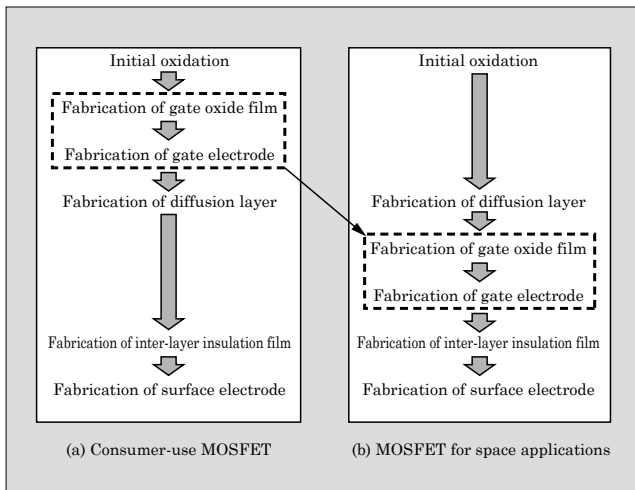


Fig.4 Process flow of consumer-use MOSFET and MOSFET for space applications

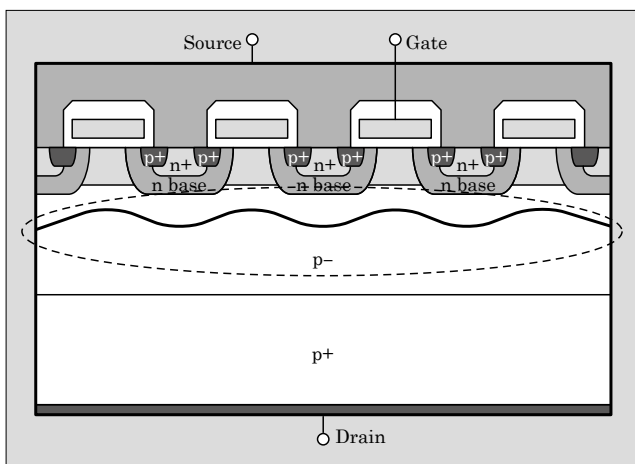


Fig.5 Cross-sectional view of active part of p-channel power MOSFET for space applications

(see Fig. 4). By applying this process, the gate oxide film acquired a lower temperature thermal history and a TID tolerance of 1,000 Gy was ensured.

3.2 Low on-resistance technology

The quasi-planer-junction (QPJ)⁽⁴⁾ technology used in Fuji Electric's consumer-use MOSFETs was also applied to this MOSFET.

With QPJ technology, n-bases are arranged in a dense configuration and the interval between the n-bases is minimized to flatten the electric field and obtain a breakdown voltage close to that of a planar pn junction (see Fig. 5). As a result, this technology lowers the resistivity of the drift layer and reduces the on-

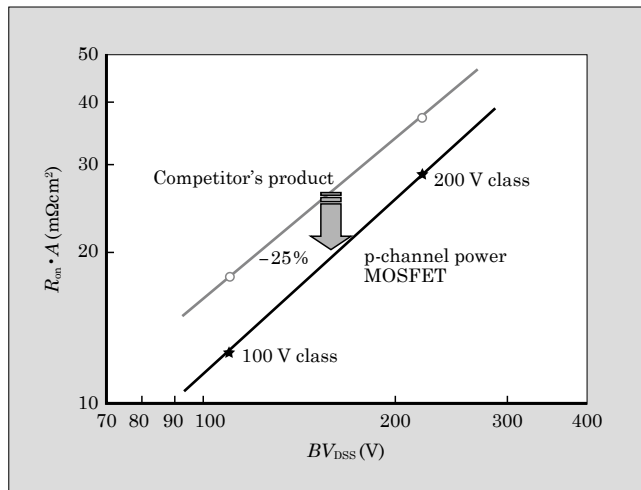


Fig.6 $R_{on} \cdot A$ versus BV_{DSS} tradeoff

resistance.

The application of this QPJ technology resulted in a 25% reduction in on-resistance per unit area compared to that of a competitor's product (see Fig. 6).

4. Postscript

This paper has introduced Fuji Electric's p-channel power MOSFET for space applications. These MOSFETs are tolerant of the space environment, i.e., they exhibit good tolerance of ionizing radiation, heavy particles and so on, and also realize the low on-resistance of consumer-use power MOSFETs.

Fuji Electric will continue to endeavor to reduce on-resistance further, improve SEE tolerance, and to contribute to the promotion of space development in Japan and overseas.

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