Forward and Reverse Stable HiPer Fast Recovery Diodes

This article introduces new families of forward and reverse HiPer Fast Recovery Diodes (FREDs) in the 200V to 400V voltage range with different current ratings. The experimental findings are consistent with numerical modelling results and demonstrate that, without using guard rings, it is possible to achieve breakdown voltages of 200 to 400V. The devices show stable blocking characteristics with low reverse current after high temperature reverse bias and humidity testing. **J.V. Subhas Chandra Bose and Peter Ingram, IXYS Semiconductor, Lampertheim, Germany**

To increase the avalanche breakdown voltage and to improve the reliability of a diode, it is necessary to shift the maximum electric field from the surface to the semiconductor interior.

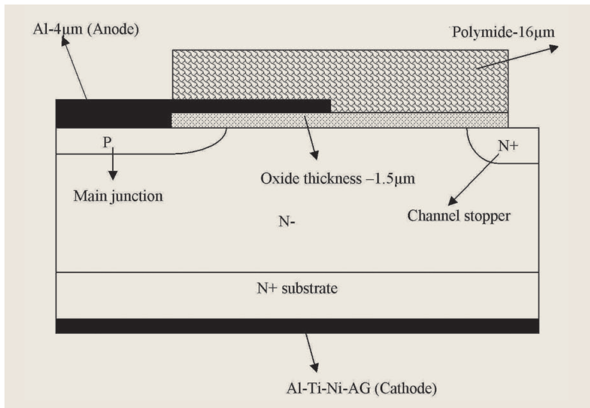

Figure 1: Cross-section of forward HiPer FRED

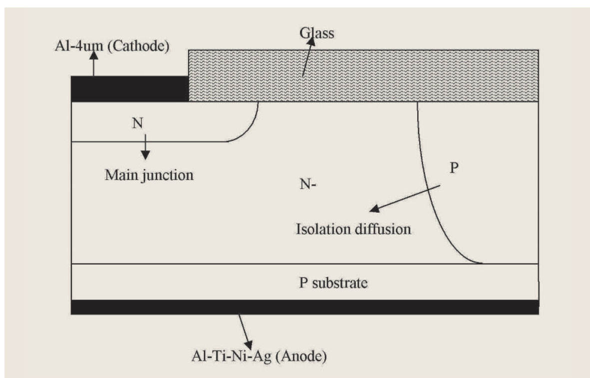

Figure 2: Cross-section of reverse HiPer FRED

Blocking and breakdown voltage alignment

In a forward planar diode, blocking voltage is limited by the region of junction curvature where maximum electric field occurs. The forward diode consists of phosphorus N-type Si region with low doping concentration. The backside is highly doped phosphorous (N+) substrate, or deep diffused phosphorus wafers in contact with the cathode metal. The front side has a boron-doped region, which is in contact with the anode metal. The blocking voltage of a forward diode can be increased by reducing the curvature effect either by using floating field limiting rings (FLRs), metal field plates or a combination of both. It has been shown that the FLR technique is sensitive to oxide charges and process variations. Optimal field plate designs involve multiple dielectric layers and gaps between metal field plates. Furthermore, using a forward diode it is possible to obtain 85 to 90% of plane parallel breakdown voltage.

In a reverse diode, it is possible to obtain 100% plane parallel breakdown voltage because of absence of junction curvature. The reverse diode consists of an N- type Si region with low doping concentration. The backside is highly doped boron (P) substrate or deep diffused boron wafers in contact with the anode metal. The front side has a phosphorus-doped region, which is in contact with a cathode metal. The 100% blocking voltage is obtained by diffusing aluminium or boron as isolation diffusion. Final passivation layer can be glass or metal field passivation.

Forward and reverse 200 to 400V diode techniques have been investigated which are insensitive to surface charge during processing and after high temperature reverse bias (HTRB) and humidity test. A new technique replaces the diffused guard rings and combination of guard rings with metal field plates. Optimisation of the structure and analysis of the breakdown voltage characteristics is carried out using ISE TCAD software. In the simulation life-time killers are not taken into account.

Numerical computations and results

The forward and reverse 200 to 400V diodes are as shown in Figure 1 and Figure 2. For example N- resistivity and thickness of 300V forward and reverse devices are 8Ω-cm and 31µm respectively. Table 1 and Table 2 show the parameters used for forward and reverse diode simulation. Figure 3 shows simulation results of impact ionisation (left) and the potential contour (right) of forward diode at breakdown voltage. Impact ionisation occurs at the main junction and the device breaks down at 300V, which is 80 to 85% of plane parallel breakdown voltage. Figure 4 shows the simulation results of impact ionisation distribution (left) and potential contours (right) of a reverse diode at breakdown voltage. Impact ionisation occurs at the bulk between PN- and device breakdown at 375V, which is plane parallel breakdown voltage.

Experimental results

For a reverse diode the starting N- thickness is high (51µm) compared to the forward diode (31µm). This is due to the fact that when the boron substrate concentration is high or the resistivity low, during deep isolation diffusion, the substrate will also diffuse into the N- epi. This process can cause a reduction in the N- thickness and consequently, the breakdown voltage is reduced. The substrate resistivity should be chosen to be a high value and isolation diffusion surface concentration or dose should be as high as possible, to reduce substrate diffusion into the N-epi during the isolation diffusion process. The boron substrate resistivity is typically 0.01Ω-cm and the boron isolation surface concentration is typically higher than $1E19cm^{-3}$. During the deep boron diffusion process the substrate diffuses less into the N- epi and therefore a reduction in the breakdown voltage would be minimal.

For example, the commercially available 30A forward diode has a chip size of 3.3mm x 3.3mm and an active area of 3mm x 3mm, whereas the reverse diode has a chip size of 3.77mm x 3.25mm and an active area 3.27mm x 2.75mm. The chip size of a reverse diode is comparable to the forward diode because the isolation diffusion area is greater. To obtain fast switching diodes or HiPer FREDs, a heavy metal such as platinum is diffused and yields devices with maximum leakage currents of 1µA at 25°C and 250µA at 125°C.

Reliability

Reliability is defined as the ability of a device to conform to its electrical and visual/mechanical specifications over a specified period of time under specified conditions at a specified confidence level.

Prior to the official release of a new device for mass manufacturing, it must undergo full qualification test. New device qualification most often requires several sets of samples for different reliability tests. The actual reliability of a device cannot be accurately determined with standard visual and electrical measurement techniques. The most important reliability tests for the electrical stability of the chip are high temperature reverse bias (HTRB) and humidity test.

HTRB test checks the ability of the samples to withstand a reverse bias while being subjected to the maximum ambient temperature that the parts are rated to withstand.

Humidity test checks the ability of the package and chip to resist moisture penetration. The sample is loaded into an environmental chamber. The relative humidity is then increased from 85 to 100% and the temperature is also elevated.

HTRB and humidity test samples are randomly selected from 25 processed wafers. The condition used for HTRB test is 80% of rated voltage at 125 or 150°C. The breakdown voltage and leakage current were measured

N- epi thickness	31µm
Boron junction depth	7µm
N+ substrate	$1E19\ cm^{-3}$
N- epi	8Ω-cm
Boron surface concentration	$5E18\ cm^{-3}$

Table 1: Parameters used for forward diode

N- epi thickness	31µm
Phosphorus junction depth	7µm
P substrate	$2E18\ cm^{-3}$
N- epi	8Ω-cm
Isolation boron surface concentration	$1E19\ cm^{-3}$

Table 2: Parameters used for reverse diode

before starting the test. 200, 300 and 400V devices were assembled into the V1-plastic package. The test was conducted for up to 1000hr and readings were taken once every 4hr. 300V Reverse diode HTRB test was carried out for up to 168hr due to a customer request. For all three-voltage classes, leakage currents are below 25µA. Furthermore, there is no increase in leakage current between pre and post measurement results.

The device characteristics are measured before starting the test. The humidity test was conducted at 85°C and at 85% relative humidity for 168hr. The device characteristics are re measured after cooling down for 2 to 3hr. Pre and post measurement results show that there is no increase in leakage current for all 4 types. The maximum leakage current at room temperature is 1µA and at 150°C for 200V 150µA, for 300V 250µA and for 400V 350µA.

By careful analysis of 30A chips of 200, 300 and 400V, we have designed and fabricated different chip sizes for different current ratings (10A/200V to 60A/300V/ 400V). All these HiPer FREDs are commercially available. Furthermore, forward HiPer FREDs are availabe with or without polymide passivation, and the reverse diodes are only available with glass passivation.

Conclusion

Simulation analysis and practical results show that using a single field plate, it is possible to obtain breakdown voltages of 200 to 400V for forward diode, and it has been demonstrated for the first time that by using reverse diode, it is possible to get ideal plane parallel breakdown voltage. Single field plate for forward diodes and isolation diffusion techniques for reverse diodes are less process sensitive and requires less chip area. Experimental results show that the device guarantees low leakage current at 25 to 150°C conditions, plus long-term stability of the blocking characteristics, even in plastic packages. Reverse HiPer FREDs with platinum as lifetime killers are a realistic new concept for power semiconductor devices.

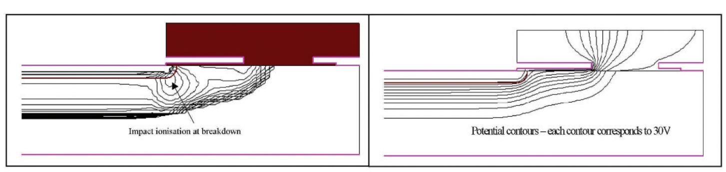

Figure 3: Forward diode impact ionisation (left) and reverse diode potential contour at a breakdown voltage of 300V

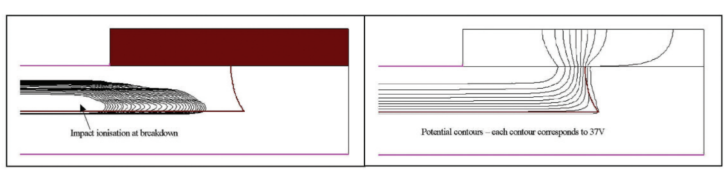

Figure 4: Forward diode impact ionisation (left) and reverse diode potential contour at a breakdown voltage of 375V