Optimized High-Voltage Diodes

In the constant quest for smaller sizes, better performance, and lower costs, Dean Technology, Inc. (DTI) has developed a new technology for producing high voltage diodes that enables the future of the product type, without introducing new materials. XOE™, eXtreme Optimized Efficiency diodes, allow users to upgrade their performance in devices of the same size made from the same materials.
Pedro H. Gonzalez, Technical Product Manager; and Griffin Caruolo, Director International Business Development, Dean Technology, Dallas, USA

Every engineer and product manager involved in electronics is familiar with the issue; new designs need to be smaller than before, have better performance than the last version, and shouldn't cost more. While accomplishing those goals is never simple, it is marginally more realistic with newer products or technologies where there is still room for large advancement through the benefits of experience. When working with legacy commodities, however, this kind of progress becomes extremely rare. Normally the only way to move performance forward or reduce size is by incorporating new materials, methods, or equipment.

High-voltage diodes are no different, they have been made using the same basic materials and processes for decades, and there has not been much overall improvement in the performance of the devices. Certainly, some new package types like surface mount have been introduced. Better quality control has allowed for slight improvements in speed, current handling, and overall voltage ratings, but neither of these have been minor steps and not a true leap forward.

High-voltage diode processing

Since the beginning of high-voltage diode fabrication, the philosophy has been to use stacked silicon to achieve the necessary high voltage characteristics essential for reliable device performance. The idea is to arrange doped silicon in a "sandwich-like" structure (as seen in Figure 1) so that the collective pieces of silicon can handle the electric field stresses which occur during device operation. This arrangement distributes the electrical stresses across the individual silicon "slices", and the method works well but has an inherent drawback which hampers efficiency.

Each slice of Silicon represents an active semiconductor voltage drop which must be overcome for proper device operation. As more slices are added to the "sandwich" the cumulative drop in voltage increases at a rate proportional to the number of slices. When the operating voltage is more than the total voltage drop a current begins to flow. It is this combination of cumulative voltage drop and current flow that affects efficiency. Such a combination produces heating in the device during operation. The heating impacts device reliability as well as limiting the operating current of the device.

Other efforts at addressing efficiency in high-voltage diodes have been attempted, through methods that replace the base Silicon semiconductor, or using far more exotic and expensive packaging materials. While these do offer performance and size benefits, the associated costs have kept them out of mainstream use.

The research and development team at Dean Technology discovered a substantially different approach. With the mindset of mitigating the inherent loss in the device and without introducing new materials or expensive equipment, they went through the production process step by step, identifying how to make corrections along the way. Diode performance is a delicate balance between many variables, each having a direct impact on the performance of the other. The team discovered that by tightly controlling all of these variables and individually designing all elements of each diode it is possible to dramatically increase the overall performance over similarly sized products using the same raw materials. This technology is called XOE™, eXtreme Optimized Efficiency.

XOE - how it is done

The performance advancements of XOE are accomplished through three main design approaches: maximizing the die size, minimizing the number of die in the diode stack, and tightly controlling the Silicon diffusion process to ensure the highest possible consistency and overall performance of each wafer. Each of these elements impacts the other two, so device

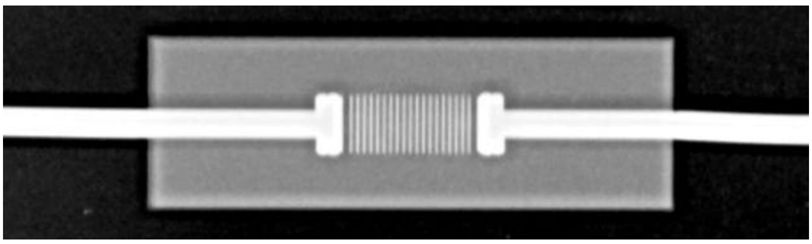


Figure 1: X-ray of common high-voltage diode

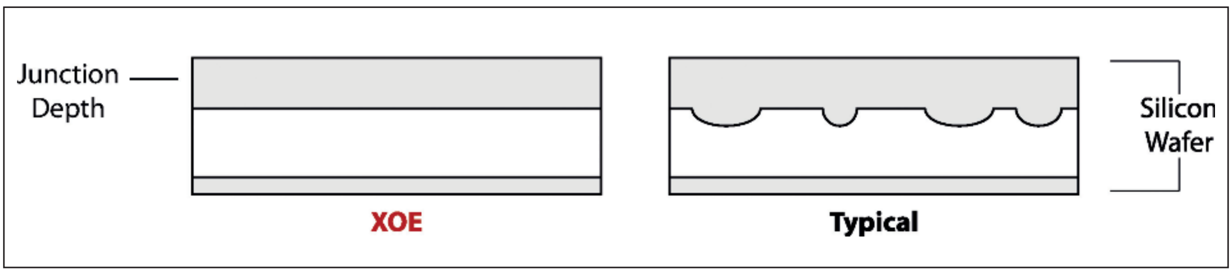
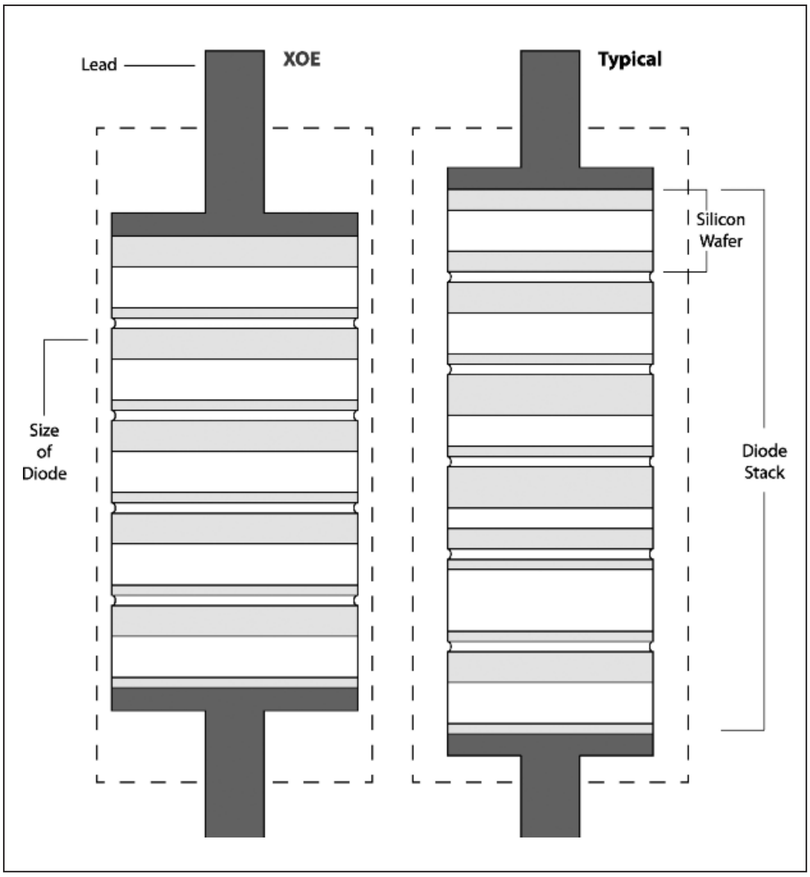


Figure 2: XOE junction depth vs. typical HV diodes



LEFT Figure 3: XOE diode construction vs. typical HV diodes

Specification	Conditions	G15FS	XGF15
Physical Size	Body Length x Body Diameter	10 mm x 3 mm	
Peak Inverse Voltage (V_{RRM})		15,000 V	
Maximum Forward Voltage Drop (V_F)	At 10 mA	25 V	10 V
	At 100 mA	-	16.5 V
	At 160 mA	-	18.5 V
Maximum Average Forward Current (I_{FAVM})	At 55°C	25 mA	80 mA
Maximum Leakage Current (I_R)	At V_{RRM}	0.2 µA	
Maximum Surge Current (I_{FSM})	At 8.3 mS	3 A	15 A
Maximum Reverse Recovery Time (T_{RR})	At Approx $I_F = 0.5\ I_{FAVM}$; $I_R = -I_{FAVM}$; $I_{RR} = -0.25\ I_{FAVM}$	100 nS	80 nS
Maximum Reverse Energy Withstand (E_{RSM})		-	500 mJ
Operating Temperature Range		-55 to 125°C	-55 to 125°C

LEFT Table 1: G15FS vs. XGF15 specification comparison

designs are done to achieve the best balance and to produce an end product that sits right in the performance sweet spot.

The first two design criteria are reasonably straight forward, though require an exceptional attention to detail. Putting as large a Silicon die as possible in the final package gives XOE products increased surface area and maximizes the current handling. Minimizing the number of die in the diode stacks leads directly to lower loss by reducing the cumulative voltage drop in the device. All of this is made possible by the third element, Silicon wafer diffusion that is focused keenly on producing the most consistent junction depth across the wafer, and consistent final thickness of each individual die.

In standard Silicon wafer diffusion for high-voltage diodes small irregularities will occur in the junction depth as dopant is diffused into the base Silicon material. This creates peaks or "weak spots" in the Silicon that have an emmense effect on the final performance. The diffusion process used in XOE creates a far more consistent junction depth, as shown in Figure 2. Limiting these weak spots in the Silicon ensures more consistent performance of each layer in the final diode stack and enables the removal of extra slices.

The consistancy that results from the XOE diffusion method also creates stacks that have more consistent performance from slice to slice. This allows for better sharing across each die in the stack, allowing the final product to produce more total voltage withstand with a lower number of slices.

The combination of these three elements allows DTI to produce a final diode product with a die stack that is far more consistent in performance and quality, offers significant performance benefits, and as illustrated in Figure 3, fits in the same size package as a typical high-voltage diode.

XOE benefits

All of this careful design, consistent quality, and predictable performance lead to truly astonishing results. Using all of the same materials, built on the same production line, and produced with the same average overall yield, DTI produces it's standard G15FS axial lead high voltage diode, and the XGF15 the XOE counterpart. Specifications for both parts are show in in Table 1 and a G15FS vs. XGF15,

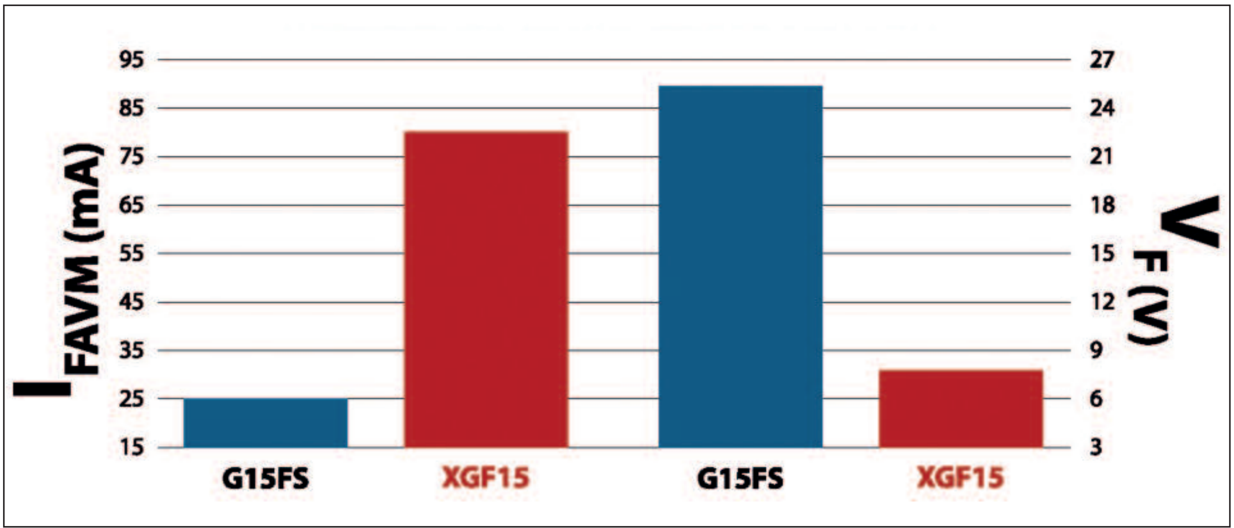


Figure 4: Comparison of G15FS vs. XGF15, IFAVM and Vf at 10 mA

I_{FAVM} and V_f at 10 mA comparison in Figure 4.

These two parts are the same physical size, have an identical voltage rating, maximum leakage current, and operating temperatures. That is where the performance similarities end. The XGF15 is significantly more efficient, showing less than half the loss of the G15FS at the same operating current, and is able to withstand a far greater forward surge current.

The lower loss of XOE diodes reduces the heat created while operating. Beyond contributing to the increased performance, this provides a more reliable product.

The consistency of the Silicon diffusion in XOE also allows DTI to rate and provide accurate maximum reverse energy withstand (ERSM) ratings for these products. The reverse energy withstand parameter is based on the ability of the diode to be driven into its avalanche region where at that point the diode will begin to flow reverse current beyond the normal leakage current. The resulting transient effect can damage a device if subjected to a prolonged duration in avalanche. The XOE platform is designed to aid in defining that parameter value due to the consistency found in the Silicon processing.

DTI has many axial lead high-voltage diodes built with XOE Technology currently available (Figure 5) and plans to release upgraded versions of all of its discrete diodes in the near future. This will include all axial lead and surface mount configurations, in all currently offered package sizes. Custom parts can also be produced using this technology to meet individual design needs for all applications that require high voltage.

Summary

By fully understanding the design and production of high voltage diodes and designing with a focus on minimizing loss and maximizing efficiency, Dean Technology is able to offer upgraded performance from similarly sized devices using the same materials. The benefits of XOE include higher current capabilities, lower voltage drop, reduced heat dissipation, better breakdown immunity from transitions into the avalanche region, and enhanced reliability for end user products and a cost effective and easy migration path for existing circuit board platforms.

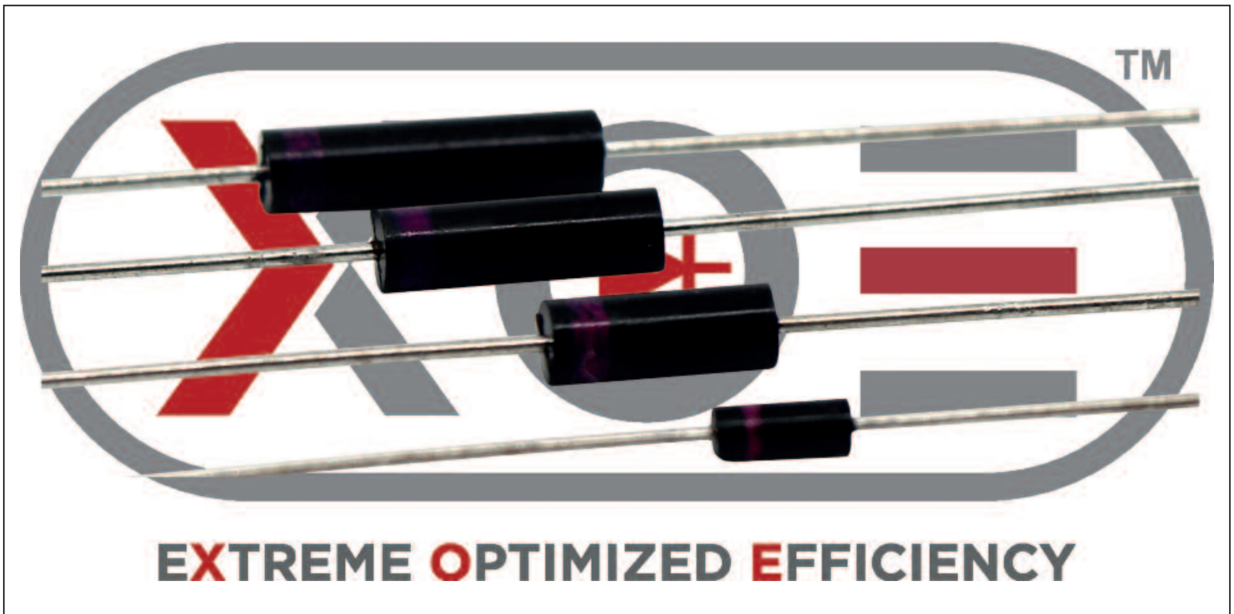


Figure 5: XOE axial lead high-voltage diodes