EOS Simulation and Failure Analysis of Metallurgically Bonded Silicon Diodes.

Alexander Teverovsky
QSS Group, Inc., Lanham, Maryland
Alexander.A.Teverovsky@gsfc.nasa.gov

Metallurgically bonded double plug non-cavity silicon diodes encapsulated in glass (type DO-35) are widely used in military and aerospace applications. In spite of a relatively simple design, these diodes have a large proportion of failures during destructive physical analysis (DPA) compared to microcircuits. Analysis of DPA jobs performed at the GSFC Parts Analysis Laboratory in 1999 shows a failure rate of 15% for diode jobs, compared to 11.5% for microcircuits. Similar results were reported by T. Devaney at Hi-Rel Laboratories, where the DPA failure rate for diodes was 44% compared to 33.1% for microcircuits. In typical military and aerospace applications, diode failures occur approximately three times more often (relative to the population of the system) than microcircuit failures. In many cases, failure is due to electrical overstress and the failure analyst is challenged to find the damage site and determine the conditions causing the failure.

Extensive analysis has been performed on secondary breakdown in diodes and transistors and the physical mechanism of this phenomenon is well-understood. Heat flow analysis is widely used to estimate failure conditions for devices damaged during EOS/ESD events. However, in most diode failures described in technical literature, failure analysis was not performed, and the relationship between overstress conditions and the location and appearance of damage has not been adequately investigated.

In this study, short pulses of forward and reverse current were applied to typical power rectifier 1N5811 diodes in order to simulate overstress conditions. Forward current pulses varied from 0.1 to 3 ms with current amplitudes varying from 200 to 1000 A were applied to one group of diodes. Reverse bias current pulses in the microsecond range with amplitudes from 2 to 400 mA (above breakdown voltage) were applied to another group. A small-step cross sectioning in combination with electrical probing, light emission microscopy, liquid crystal technique, and chemical staining were used to reveal and compare damage in three groups of diodes: two overstressed groups and the third group which had failed during burn-in electrical testing.

Failure mechanisms and peculiarities of damage created in these diodes and several case histories related to different types of diodes are discussed.

Analysis showed the following:

1. Small-step cross-sectioning technique in combination with electrical probing, light emission microscopy, liquid crystal technique, and chemical staining was successfully used to reveal damage in the failed metallurgically bonded diodes.

2. In all cases damage to the diodes was caused by local overheating above the melting temperature of silicon. Depending on the dissipated power and the pulse duration the overstress caused changes in the characteristics of the diodes varying from a hard short circuit with a resistance of less than 1 Ohm, to a subtle increase in the leakage current and/or decrease in the breakdown voltage that might not exceed the specification limits.

3. Hard shorts in the diodes with a resistance of less than 1 Ohm were caused by a three-dimensional web of silver alloy with a thickness of approximately 0.1 µm which was formed across re-crystallized silicon, shorting the terminals of the diode. Shorts with a resistance from several Ω to KΩ were caused by the re-solidification of melted silicon/silver/nickel alloy within the P-N junction area. Softening of the reverse I-V curves was due to damage a few micrometers in size with only minor disruptions in the P-N junction area.

4. Relatively large forward current pulses of more than 1 ms and less than 400 A resulted in smooth, sphere-like damage with a size of 100 to 250 µm, located mostly in the central area of the die. Shorter, but higher amplitude pulses caused damage of 25 to 100 µm located at the mesa-slug interface. Heat transfer simulations showed that failures caused by forward current pulses in the millisecond range are due to fundamental thermal properties of silicon. These are not related to possible minor irregularities in the junction and/or metallization contacts. The Wunsch-Bell model can be used to estimate conditions of the forward bias EOS events.

5. The appearance of damage in TVS diodes overstressed by reverse voltage pulses in the millisecond range, is similar to diodes overstressed with forward current. This suggests a similarity in the heat transfer mechanisms in these diodes during forward and reverse voltage EOS events.

6. Short reverse voltage spikes of 1 to 3 µs duration above the breakdown level, and with a current of 10 to 200 mA in amplitude, resulted in surface breakdown and exhibited damage at the mesa-glass interface. The damage consisted of melted silicon with dimension of 5 to 20 microns and caused a softening of the reverse I-V curves and a decrease in the breakdown voltage.

The diodes that failed during burn-in testing had relatively high short circuit resistance measured in KΩ, caused by a small volume of melted and re-crystallized silicon/silver/nickel alloy measuring 5 to 10 µm in the bulk of the diodes. The small amount of damage initially caused in diodes by a short, microsecond range reverse voltage spike can be significantly enlarged providing a sufficient current follows through the weakened site once the initial failure has occurred.

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