The Drive to Miniaturize - 0201 Flip Chip Silicon Schottky Diodes

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Introduction

The incessant drive to miniaturize electronic systems places pressure on semiconductor manufacturers to offer ever-smaller components. This trend is rapidly approaching its logical conclusion, which is the elimination of the semiconductor's package altogether in favor of a die which can be directly mounted to a printed circuit board (PCB) with automated assembly equipment.

The first two members of a family of packageless, silicon flip chip Schottky diodes have been developed and introduced as a direct result of this miniaturization trend: SMS7621-096 Low Barrier Schottky Diode and SMS7630-093 Zero Bias Detector Schottky Diode. The packageless flip chip devices not only address the requirements of miniaturization, but they also offer performance benefits.

Figure 1: Ceramic, Hermetic Surface Mount Diode Package

Figure 2: The SOT-23 Package

Figure 4: The SC-79 Package

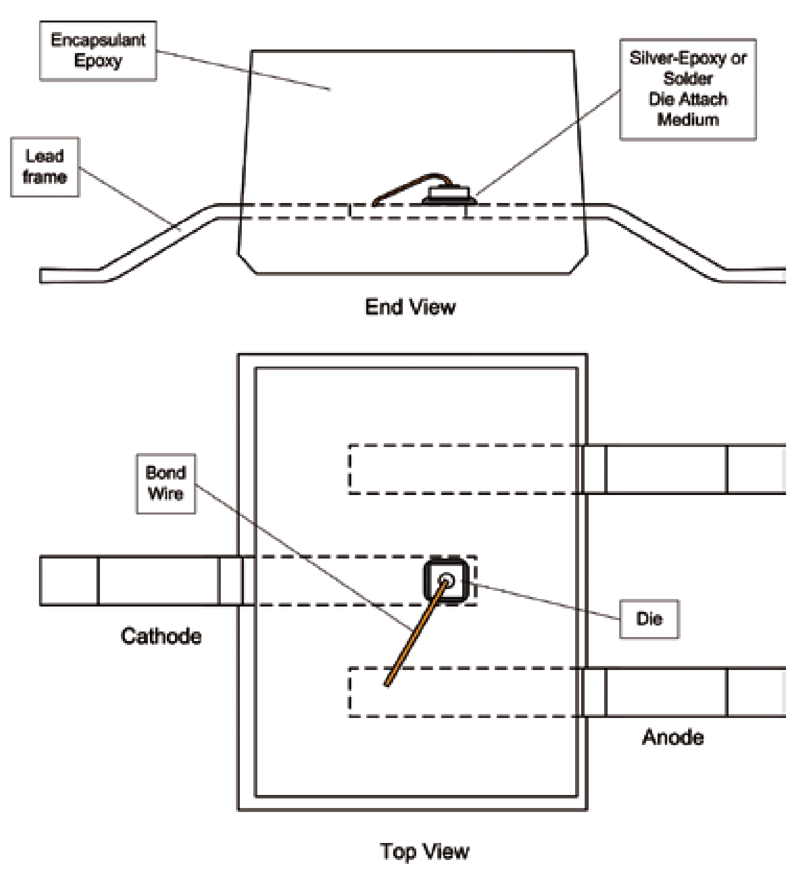

Figure 3: The SOT-23 Package Internal Construction Note: This drawing is not to scale. It is intended to illustrate the construction of the SOT-23 package only.

The Drive to Miniaturize

Diode packages have shrunk continually and significantly over the past decades. Early surface mount RF/microwave diode packages typically comprised ceramic bodies with metal leads brazed to their undersides, an example of which is shown in Figure 1. The square, ceramic portion of these packages are as small as 1.78 mm on a side. These packages offer many performance advantages, such as hermeticity, low parasitic inductance, and low parasitic capacitance, but they can be costly with their prices in the few dollar range. These packages are not amenable to die attach or wire bond assembly with automated machinery; skilled assemblers are required for some of the assembly operations, especially wire bonding.

Lead-framed surface mount plastic packages were introduced in the late 20th century. These packages are much less costly to produce than ceramic packages. They can be fully assembled with automated machinery rather than by skilled human assemblers. The constituent components of these packages are low cost. The required PCB foot prints of these packages are, in many cases, much smaller than those required for the ceramic package counterparts.

A major advantage of these plastic packaged devices is their compatibility with pick-and-place automated PCB assembly equipment. Disadvantages of these packages include higher parasitic reactances (especially series inductance) and in many cases, higher thermal resistance.

Leadless plastic packages have been available for the past few years. These packages eliminate the external leads of gull wing packages, such as the SOT-23 family of packages (Figure 2), which further reduces the required PCB area as well as series inductance. An additional benefit of these packages is lower height when mounted on a PCB, a factor that came into play with the advent of package height restrictions for PCMCIA cards and has become much more important as cellular telephones have become almost paper thin. Indeed, some original equipment manufacturers require package height to be 0.4 mm maximum.

A cross-sectional view and a top view of a diode mounted in an SOT-23 package are shown in Figure 3. While this drawing is not precisely drawn to scale, it is representative of the internal construction of a single diode in a SOT-23 package.

The minimum thickness of this package is determined by a combination of several factors. The gull wing lead frame of this package establishes the height of the die attach interface. The thickness of the die, which is typically 0.127 to 0.2554 mm for most RF/microwave diodes, sets the level at which one end of the internal bond wire is terminated. The bond wire must have a loop to provide stress relief so that the mismatches in the thermal coefficients of expansion between the bond wire and the encapsulant epoxy do not break the wire when the diode experiences changes in temperature. The total of the internal lead frame height, die thickness, and the stress relief loop height set the lower limit for the total package thickness. Of course, in order to fully protect and encapsulate the bond wire, the total package height must be a bit higher than this lower bound. The typical height specifications for the SOT-23 package are 0.89 mm minimum, 1.12 mm maximum.

Smaller packages, such as the SC-79, shown in Figures 4 and 5, are thinner than the SOT-23 but do not meet some current and many future requirements for maximum package height. The typical height specifications for the SC-79 package are 0.50 mm minimum, 0.70 mm maximum.

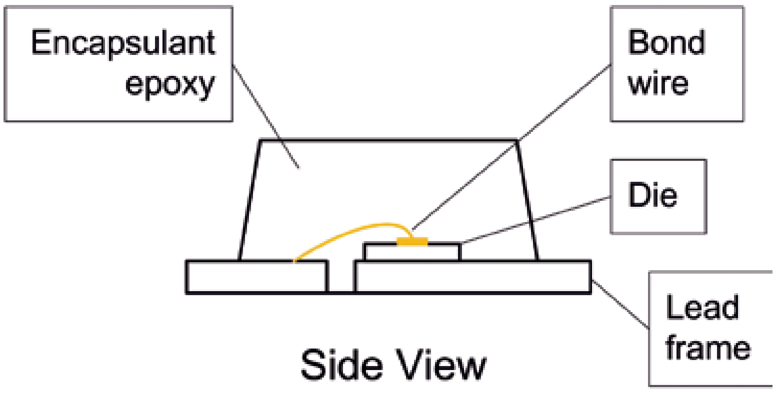

Figure 5: SC-79 Internal Construction
Note: Drawing not to scale

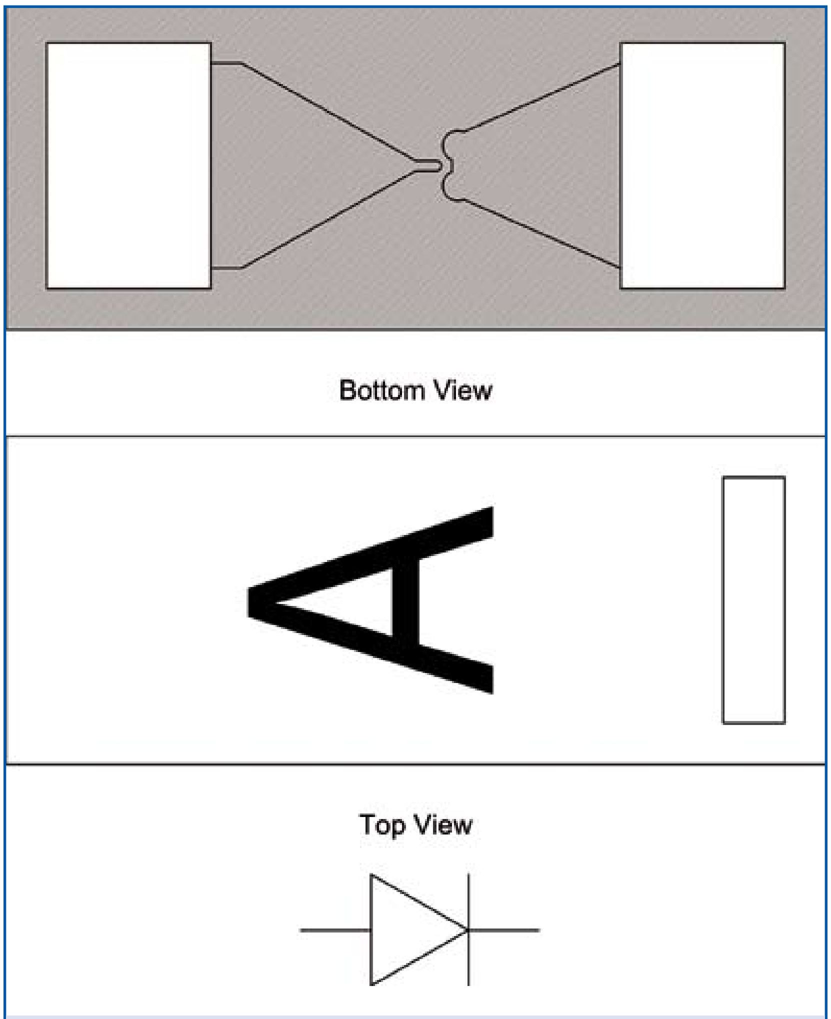

Figure 7: SMS7621-096

Enter the Flip Chip

The new family of flip chip Schottky diodes offers many advantages over packaged diodes. These advantages include, but are not limited to, lower maximum height, much lower parasitic reactances, and smaller PCB foot print. These parts have been designed to be compatible with the 0201 footprint.

The SMS7621-096 0201 Flip Chip Silicon Schottky Diode

The SMS7621-096 low barrier Schottky diode is shown in Figure 6.

The active junction of this diode resides on the surface of the part, centered between the metal terminals as shown in Figure 7.

This diode is fabricated utilizing Skyworks' proven silicon Schottky diode technology. With the exception of the flip chip configuration of the die, this diode is identical to the other members of the SMS7621 family, hundreds of millions of which have been produced and used in systems that range from signal amplitude measurement in cellular telephone base station power amplifiers to mixers in 24 GHz Doppler radar transceivers.

The Schottky diode junction is formed by plating a very pure metal onto a wafer that has been doped with n-type dopant atoms. As soon as these materials are brought into contact and thermal equilibrium is established, their Fermi levels become equal. Electrons from the semiconductor lower their energy level by flowing into the metal. Charge accumulates at the interface, distorting the energy bands in the semiconductor. This creates an energy barrier, known as the Schottky barrier, which prevents more electrons from flowing from the n-type material into the metal without assistance from an external energy source of the correct polarity to elevate their energy above that of the Schottky barrier height. External energy of the opposite polarity increases the barrier height, thus preventing conduction. (Cory, 2009) Additional metal is plated on top of a dielectric layer to connect the diode's anode and cathode to their respective terminals located at opposite ends of the die.

In addition to reduction in size (especially total height), the packageless 0201 mechanical configuration offers another important benefit: the parasitic capacitance associated with a diode package is virtually eliminated, and the parasitic inductance of the diode is substantially reduced.

Figure 6: SMS7621-096 Silicon Flip Chip 0201 Schottky Diode

The equivalent circuit of a packaged diode is shown in Figure 8. This circuit comprises the diode die, embedded in a circuit which contains the parasitic package capacitance and parasitic inductance primarily produced by the package and the internal bond wire.

These parasitic reactances become increasingly significant with increasing frequency. As frequency increases, the reactance of the series inductance, L_S, does the same. The impedance of L_S reduces the signal current that is present through the diode junction, which in the case of a Schottky diode reduces its efficiency as a detector. Likewise, as frequency increases the capacitive reactance of the package capacitance, C_P, decreases. Since this reactance is in shunt with the diode junction, it reduces the signal voltage across the junction, decreasing the diode's efficiency.

The flip chip configuration eliminates the bond wire that would be required for a packaged device. It also eliminates the lead frame conductors or package terminals. The elimination of these two constituents of series inductance reduce the total series inductance of the flip chip to less than 150 pH. By comparison, the series inductance of the SOT-23 package is approximately 1.8 nH.

The elimination of the bond wire, lead frame elements and encapsulant epoxy virtually eliminates the parallel package capacitance. The package capacitance for an SOT-23 can be as large as 100 fF, which appears to be a small number until one considers that it produces capacitive reactance of 66 Ω at 24 GHz, for example.

This reduction in parasitic reactances allows this diode to perform very well at very high frequencies. For example, the SMS7621-096 has been designed into a 24 GHz Doppler radar gun that will be utilized in consumer sports applications, such as velocity measurement of baseballs and ice hockey pucks. The efficiency and 1/f noise of the SMS7621-096 diode in this application are excellent.

The SMS7630-093 0201 Silicon Flip Chip Zero Bias Detector Diode

The SMS7630-093 (Figures 9 and 10) is a flip chip Schottky diode fabricated with p-type silicon. The type of metal that contacts the p-type silicon is selected to produce a very low barrier height, in order to produce a very sensitive detector. This barrier height is lower than that of a low barrier Schottky diode and is commonly known as a zero bias detector (ZBD) barrier height.

The appellation “ZBD” can be a source of confusion; any Schottky diode can be used as a detector without requiring an external bias source. However, the higher the barrier height the less sensitive the diode is to very small signals. If the diode is slightly forward biased with an external current source, sensitivity to small signals can be improved. The ZBD was developed to eliminate the need to use an external bias source in a very sensitive detector, thus the nomenclature “ZBD.” (Cory, 2009)

Due to the construction of the ZBD junction, the polarity of this diode is the reverse of that of the SMS7621-096. That is, the finger of metal that contacts the silicon is the cathode of the SMS7630-093. Otherwise, the mechanical layout of the SMS7630-093 is identical to that of the SMS7621-096, so the reduction in parasitic reactances and the corresponding improvements in performance described above also apply to the SMS7630-093.

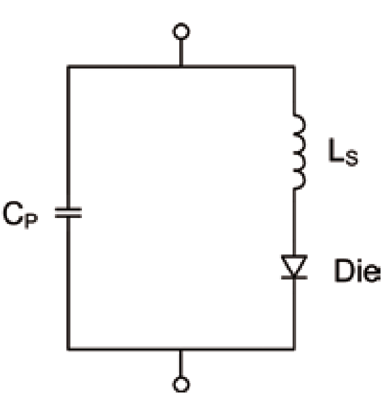

Figure 8: Packaged Diode Equivalent Circuit

Figure 9: SMS7630-093 Silicon Flip Chip 0201 Zero Bias Detector Diode

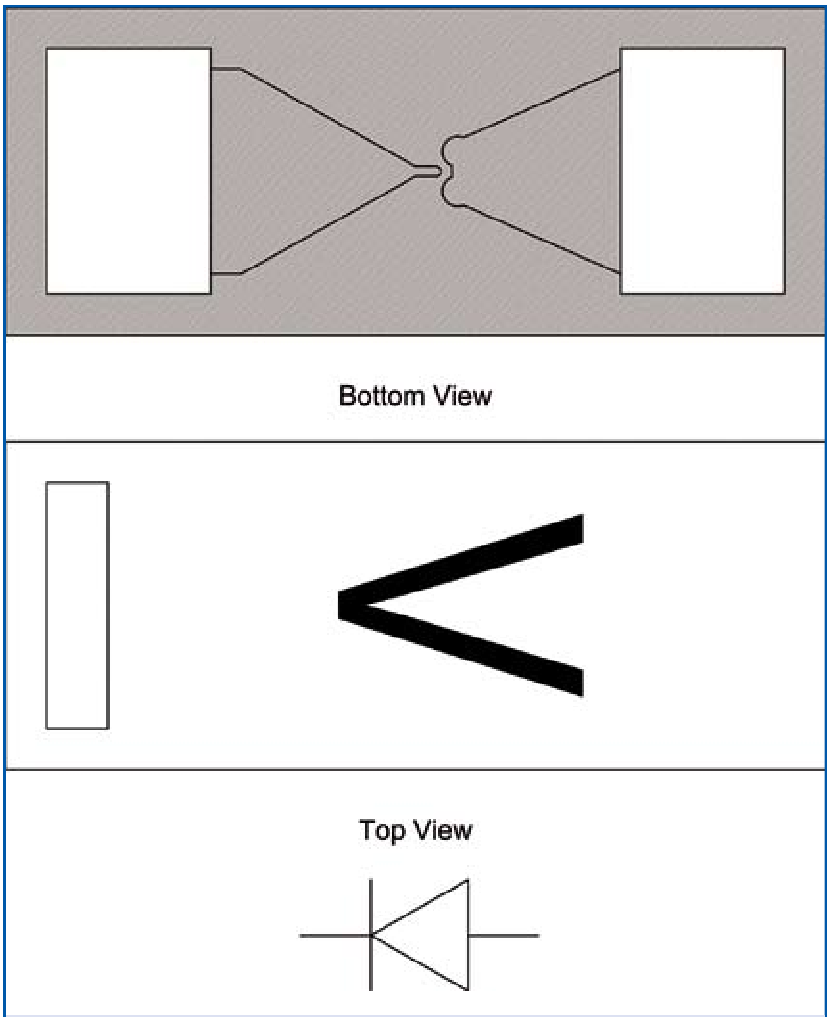

Figure 10: SMS7630-093

Putting the SMS7621-096 or SMS7630-093 to Work

The SMS7621-096 and SMS7630-093 may be attached to a PCB with solder paste. Both devices are available in tape and reel or in GelPak™ for smaller quantities. These devices are fully compliant with current RoHS regulations and are Green products. Please refer to Skyworks’ Web site for the definition of Green: http://www.skyworksinc.com/downloads/green_initiative/skyworks_greendefinition.pdf

In addition, the data sheets for these diodes, which contain electrical specifications, SPICE parameters, outline drawings, suggested PCB land patterns, and tape and reel information are available at www.skyworksinc.com.

Conclusion

Skyworks Solutions has introduced a new family of 0201 silicon flip chip Schottky diodes: the low barrier height SMS7621-096 and the SMS7630-093 ZBD. These devices offer excellent performance at high frequency due to the virtual elimination of parasitic package reactances by virtue of the elimination of diode packages.

References

Cory, R. (2009, February). Schottky Diodes. *Microwave Products Digest.*