High-Temperature Semiconductor Solutions

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The use of hydrocarbons like oil and natural gas continue to be a critical source of the world's energy for the near and likely intermediate term. Since the beginning of drilling for these resources, technology has allowed ever-growing efficiencies and increased effectiveness of oil exploration and extraction equipment. As the world has removed these non-renewable resources, they are becoming increasingly difficult to obtain. Although there is still an abundance of oil and gas, the future requires continued technological improvement to access deposits that are found ever deeper underground. As these wells become deeper they also become extremely hot, and using high-reliability, high-temperature electronics for down hole drilling equipment is necessary.

Most of the current oil and gas wells have temperature requirements for electronics of less than 175°C, but many new wells must be drilled to 5 km and beyond where temperatures can exceed 200°C. This means that solutions need to be found to provide electronics to support the many different measurements required for these extreme environments. With high vibration, shock, pressure, and temperature, the environmental conditions provide some of the worst possible for semiconductors – without including the fact that they are typically also exposed to humidity, oil, mud, and corrosive chemicals.

These ruggedized electronics are built to provide the drilling companies as much information about the well they are drilling as possible. New techniques are developed and expanding capabilities allow tools that are mounted right above the drill bits to provide a wide variety of measurements to make drilling more effective. Logging of the well bore provides drillers with details of the location and position of the drill string, and detailed formation evaluation.

Measurement while drilling (MWD) and logging while drilling (LWD) equipment use many different sensors and inputs that have to go through data acquisition systems designed to capture information such as resistivity, density, porosity, and data from radioactivity and sonic sensors. These inputs provide details on the formations and productivity of the surrounding rock, which are critical details when trying to steer the drill bit to a desired location from kilometers above.

Reliability of this equipment is crucial to keep down-time at a minimum and eliminate the time consuming and costly process of replacing these tools while at a drill site. Failures can cost production time and effort, and inaccurate drilling can turn into oil and gas that can not be recovered.

The semiconductors used for most of the current high-temperature electronics designed for down-hole drilling typically are qualified only to 125oC. There are many issues with using parts not specified for extreme high temperatures like silicon reliability, temperature performance, and package reliability. The qualification and characterization of semiconductors at high temperatures are

important to make sure that functionality, quality, and reliability all meet the needs of the intended application. As the typical drilling requirement is 1,000 hours, the use of qualified devices can be provided on a number of semiconductor process technologies, including both bulk silicon (Si) and silicon on insulator (SOI).

High Temperature Semiconductor Qualification

There are several failure mechanisms for semiconductor technology at high temperatures. Some are found in the silicon and some are due to package issues. The qualification of any high-temperature device needs to take into account the silicon reliability, package, and operating life of the overall device.

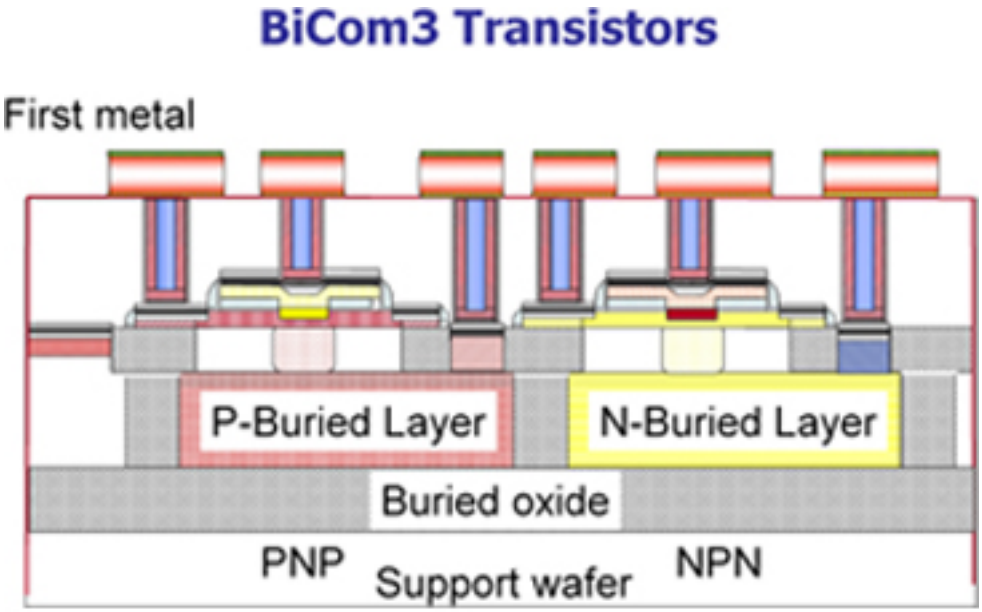

Figure 1. BiCom³ transistors.

As temperatures increase, semiconductor device characteristics degrade due to increased junction current leakage, intrinsic carrier density, and variances in threshold voltages and carrier mobility. The typical limit for standard silicon devices is around 200oC and around 300oC for SOI parts. The biggest difference between these process technologies is the improved leakage current of the transistors in SOI at higher temperatures. Figure 1 shows an example of the BiCom3 high-speed BiCMOS SOI process that is designed for high-speed operation with silicon-germanium (SiGe) bipolar transistors. The buried oxide layer provides insulation to prevent leakage current to the substrate.

Although the SOI process provides lower leakage currents, reliability failures common to both bulk Si and SOI must be understood for high-temperature qualification. Electromigration (EM) occurs in the metal conductors as current flow moves the atoms causing degradation and eventual open circuits. Time dependent dielectric breakdown (TDDB) occurs in the gate oxides. Both failure modes are accelerated at higher temperatures. A high-temperature semiconductor design and technology should be verified to have sufficient checks for EM, negative bias

temperature instability, TDDB, and hot carrier injection. When a new part is released it should receive a full characterization across temperature to make sure it meets all the required specifications.

For 200°C applications in such harsh environments, the package normally used is a ceramic hermetic package or hermetic multichip module (MCM). These packages must be able to withstand extended temperatures, as well as the violent movements at the bottom of an oil well. Standard package qualification testing includes:

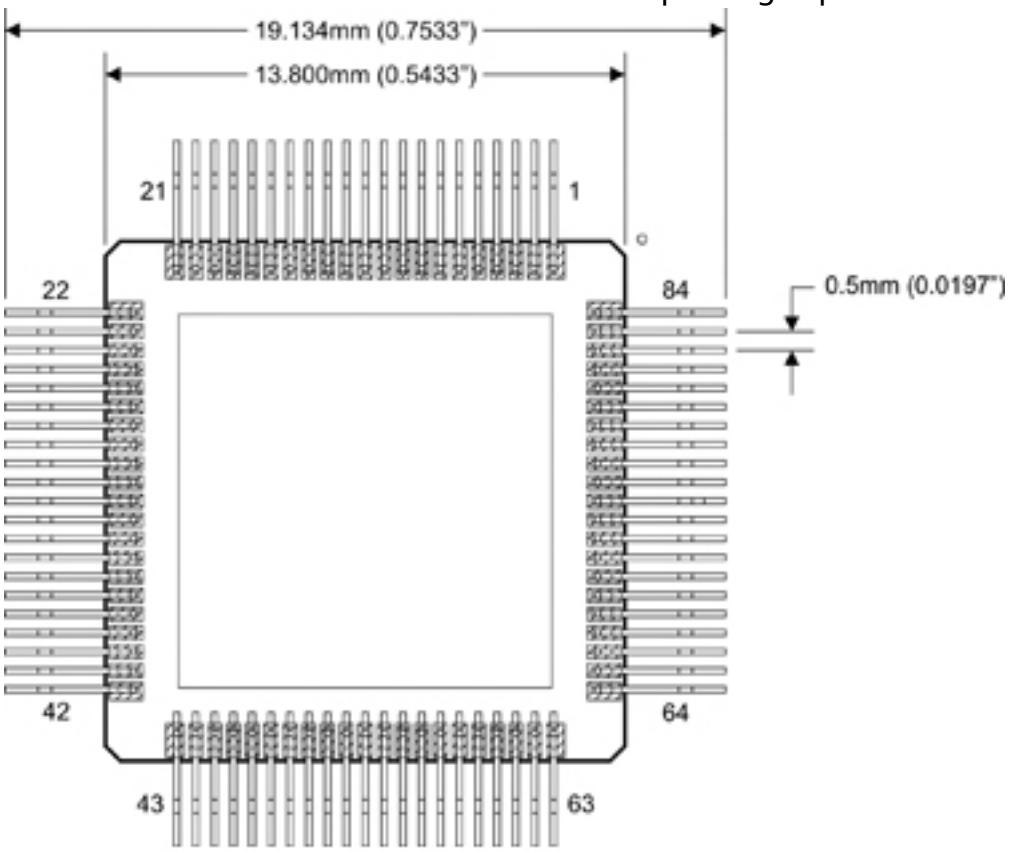

Figure 2. An 84-pin trim and formed ceramic flatpack package outlines size in mm (inches).

* bond strength/intermetallics
* mechanical shock
* variable frequency vibration
* temperature cycle
* hermetic test
* thermal shock

Since size is a big issue in fitting electronics in down hole tools, smaller packages and access to known good die (KGD) for MCMs is needed. An example of a package for high-temperature applications is the 84-pin ceramic quad flatpack (See Figure 2) that allows higher pin counts for parts like the SM470R1B1M-HT ARM7-based microcontroller to fit on one-inch wide boards needed for these space limited applications.

For applications that may only reach 175ºC, options for packaging are available in

traditional plastic packages. High-temperature plastic packages offer operating temperature above 125ºC, since these packages are designed and assembled with extreme high temperatures in mind. Qualified high-temperature mold compounds, die attach materials, and die-bonding techniques ensure operation to meet these extended temperature ranges.

One other aspect of qualification for these harsh environment applications happens after the parts are characterized and packaged into appropriate packaging. High-temperature life test data is collected for each release in order to provide at least 1,000 hours operating life. This test needs to take into consideration the wafer fabrication process, device function, and feature size. As an example, Texas Instruments high temperature products are put through a 2,000 hour burn-in life test to provide final qualification for all new releases. The operating life chart for the ADS1278-HT eight-channel, 24-bit analog-to-digital converter (ADC) is shown in Figure 3.

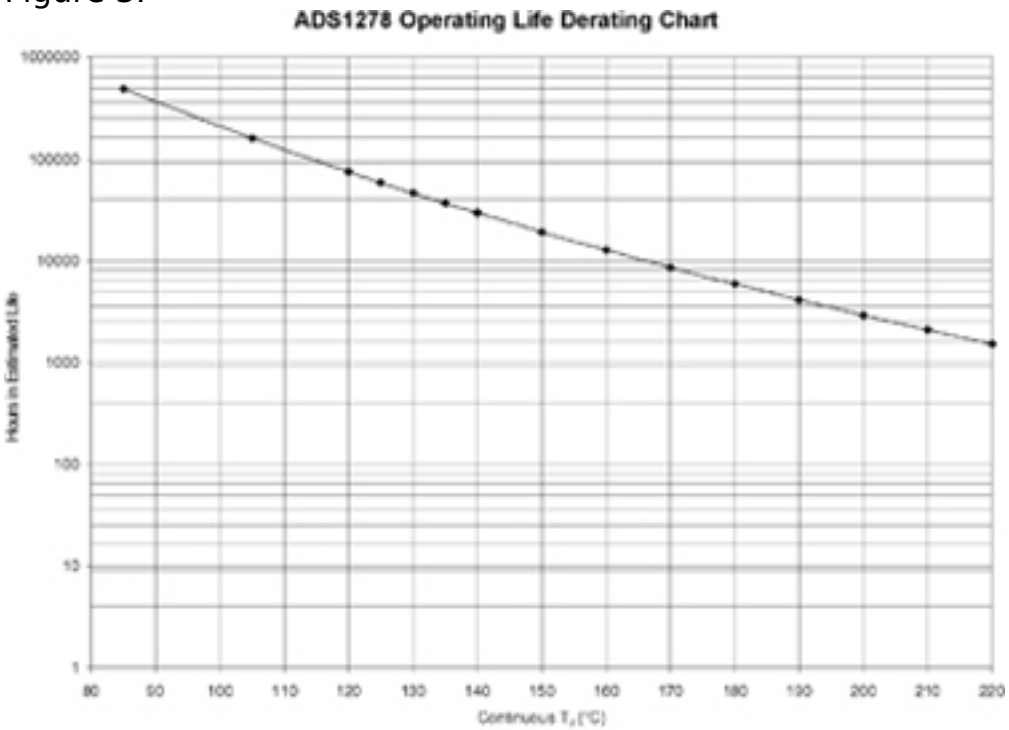

Figure 3. Operating life derating chart.

With the increasing temperature requirements for new applications in the oil drilling, aviation, and industrial markets, designers are going to need a complete portfolio of high-temperature devices to address operating temperatures from 150ºC all the way to 220ºC.

* Download a datasheet and other technical documents for the ADS1278-HT here [1].

* For more information about other high-temperature devices, please visit: www.ti.com/ht [2].

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[1] http://www.ti.com/product/ads1278-ht
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