Aerospace R & D Benefits Future Geothermal Reservoir Monitoring

Randy A. Normann and Joseph A. Henfling

Sandia National Laboratories, Albuquerque, NM, USA

Keywords

Reservoir, monitoring, high temperature electronics, silicon-on-insulator, SOI, SiC, unshielded, sensors, drilling, logging, tool, batteries

ABSTRACT

This report covers the basic design of the Sandia downhole geothermal reservoir monitoring system. The monitoring system can operate continuously at temperatures up to 240°C (464°F) while measuring small pressure and temperature changes in reservoirs. Future improvements in the existing system will come from research and development programs by such agencies as NASA, JPL, USAF and NETL. An explanation of the benefits of this research to the Geothermal HT electronics program will be given.

Introduction

Unshielded electronic control and measurement systems that can operate for many years at 300°C (572°F) are technically achievable. High temperature (HT) semiconductor technology has reached the point of operating at these temperatures. There are two principle HT semiconductor technologies, SOI (Silicon-On-Insulator) and SiC (Silicon-Carbide). While the majority of the HT components available today are fabricated using SOI technology, SiC is being utilized in extreme temperature applications. With SiC semiconductor technology, reliable operation at temperatures in excess of 450°C (842°F) is possible!

However, making these technologies commercially viable is more difficult. Over the past few years, Sandia's Geothermal program has been helping to establish newly initiated high temperature electronic product lines that meet the requirements of the geothermal industry. This way, new HT products have dual-use to help maintain commercial production. A brief discussion is given on other development programs leading to new HT components and sensors.

The development of high temperature electronics and sensors can facilitate the advancement of all aspects of geothermal power production--from futuristic power plant controls, which can look down into production and re-injection wells for control data, to drilling and logging tools with nearly indefinite life inside the well.

Clearly, high temperature electronics is an enabling technology in all aspects of future geothermal developments. However, one of the first and most important applications of high temperature electronics will be tools designed to help keep geothermal power plants on-line. [3] High temperature tools can impact this trend almost immediately by giving operators the ability to monitor reservoir characteristics on a much more frequent basis, or in the case of a downhole reservoir monitoring system, continuous real-time data is achieved. This is the area in which new tools will immediately benefit the industry through improvements in production, re-injection and well maintenance strategies.

Based on SOI technology originally developed for aircraft engine controls [1], Sandia has developed and field-tested a PT (Pressure/Temperature) logging tool and three reservoir monitoring tools. After a brief discussion on Sandia's approach to high temperature electronics and a look at the next generation HT components (both SOI and SiC), the remainder of this paper will elaborate on the high temperature downhole reservoir monitoring system.

Approach

The Sandia approach is simple: "Adapt and expand high temperature electronics technology to downhole applications." For example, the aircraft industry has been the driving force for most commercial HT electronic components. The components needed for electronic aircraft engine controllers are nearly identical to the components needed for a simple logging tool.

Most geothermal applications will require features and components not required for aircraft. For example, special batteries and narrow tubular packaging must be developed for unshielded geothermal logging tools [2]. Once new high temperature designs are demonstrated for geothermal wellbore applications, the geothermal industry will gain never-before-realized instrumentation capabilities that will lead to new approaches in well logging and reservoir characterization.

Sandia realizes that many factors are stifling the development of high temperature tools by the geothermal service companies. Some of these factors include: 1) lack of SOI devices to complete the SOI component set available from Honeywell; 2) a means to reduce the learning curve required to develop a downhole tool; 3) identifying and testing components and sensors needed to build a complete system; 4) development of high temperature (250-300°C) batteries [3]; and 5) fabrication issues such as the development of better solders and fluxes.

Sandia has been working to solve the above issues, and has designed a custom ASIC (Application Specific Integrated Circuit) to complement the SOI components available from Honeywell. The ASIC design was then fabricated at Honeywell using their SOI technology. Sandia has given Honeywell permission to make this SOI device commercially available. The part number for this device is HT83SNL00. Sandia has designed and assembled "learning kits" to decrease the development time of designing tools. Under the DOE sponsored Sandia High-Temperature Electronics program, we have an ongoing testing and evaluation program to identify and qualify suitable high temperature components and sensors. Geothermal service companies can utilize Sandia component information without restiction, which will result in reduced cost to develop high temperature Dewarless tools that were not possible even a short time ago.[4]

As more and more HT tools are successfully fielded, the need for HT electronics will increase. The proven reliability of SOI and SiC technologies has helped to spark ideas for many additional HT applications. Agencies such as NASA, JPL, USAF and NETL now have active HT programs. The components that are developed for these programs will enhance the capabilities of all HT applications. Geothermal temperature requirements are comparable to the aforementioned programs; by providing input during the development stage of these components, many will be suited for future downhole reservoir monitoring and drilling tools. A list of these HT component sources follows:

Sources of New HT Components

NASA

NASA is an active supporter of the HT electronics industry. NASA has several planned, unmanned missions to Venus. Venus's temperature at the surface is a hot, 460°C! SOI semiconductor technology will not be adequate for these extreme temperatures. As such, NASA has invested resources to make the SiC semiconductor technology more affordable. NASA has also been a supporter of the HT programs at both the Jet Propulsion Laboratory and Glenn Research Center.

Sandia will be receiving a SiC pressure sensor designed for 600°C operation from the NASA-Glenn Research Center. This technology has considerable potential for long-term wellbore pressure monitoring within geothermal wells. This pressure sensor is being made commercial by Sienna Technologies, Inc. Sandia has promised to test this sensor for measurement drift and hydrogen degradation at 320°C (608°F). We expect this sensor to pass laboratory testing and move on to actual well bore deployment in 2005.

Jet Propulsion Laboratory

The Jet Propulsion Laboratory (JPL) is starting a HT University Consortium to develop new system components needed to support upcoming missions to Venus. One of the first components being *considered* for development is a seismic sensor system. Such a seismic system could be used for long term monitoring of earthquake data and hydro fracturing deep within the geothermal reservoir to enhance production.

US Air Force

The USAF has a program to develop the More Electric Aircraft (MEA), where distributed electric power systems will displace heavy hydraulic systems. New electronics are needed for high-temperature areas of the engine. Naturally, these new high-temperature electronics must highly reliable, operating without failure for many years.

One of the components needed for this program is a SiC power transistor. Power transistors have been developed and are now becoming commercially available from SemiSouth Laboratories. Sandia has already received eight test samples for evaluation. These transistors are rated for 6 amps, 200-600 volts at 300°C. Future devices are planned for 100 amperes.

The newly developed SiC transistor can be used for driving signals up very long cables or controlling large motors downhole. In fact, the idea of driving large electric drilling motors downhole has caught the attention of the oil patch.

National Energy Technology Laboratory, NETL

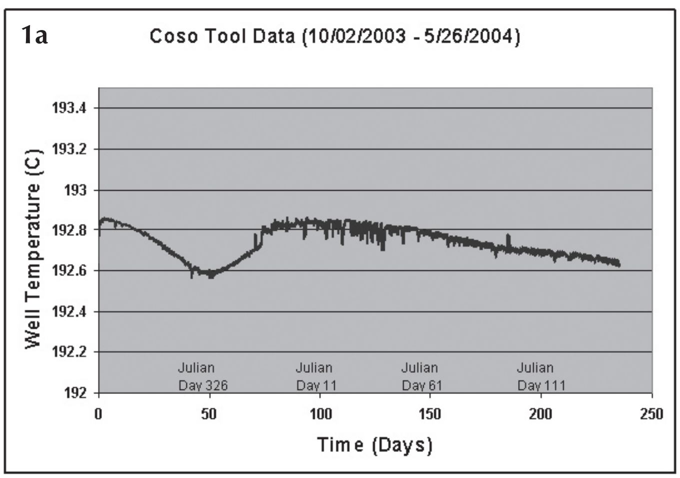
The NETL is working with a number of private companies under a Joint Industry Partnership to develop several HT SOI devices. This partnership was formed to support deep (>20,000ft) natural gas drilling tools. Deep natural gas drilling is very expensive, requiring tools to operate reliably at temperatures greater than 200°C.

Sandia is working with NETL to help insure these new components meet the needs of a broad range of drilling and logging applications.

Reservoir Monitoring System

To date, three reservoir monitoring systems have been successfully deployed. The first two systems were funded by the USGS to help in their work in reliably predicting volcanic unrest. Several examples of pre-eruptive groundwater pressure changes show that fluid pressure monitoring can be a valuable tool for detecting volcanic unrest. Subsurface magma movement affects fluid pressure by deforming the earth's crust and heating subsurface fluids. Moreover, intriguing interactions between earthquakes and volcanic unrest are believed to be mediated by fluid-pressure effects. By monitoring downhole pressure and temperature with very high resolution, and interpreting the resulting data in the context of crustal deformation, seismicity, and gas emission, valuable volcanic information may be gained from these tools. The two systems are currently installed in moderate temperature wells located near Mammoth Lakes, CA. One of these tools will be redeployed this summer in a moderate temperature well located in Hawaii.

The third system was deployed in a Coso Naval Test Range well. The tool has been installed within the well at 3100 ft using wire in tubing. At this point the nominal temperature is 192°C (379°F). This is the hottest location within the well. Prior to the tool going into the well, the tool was oven tested for one month at temperatures between 180 and 200°C. The purpose of this field test is to demonstrate the increased reliability gained when using manufacturer-qualified high-temperature electronic components. Sandia is working with a large number of manufacturers to build a complete logging tool using only commercially available components. We hope to continue this test for the next two years. To date, this system has been deployed for approximately 180 days. Combining the oven tests prior to deployment with the ongoing field test, the tool is approaching 5000 hours at elevated temperatures. The downhole reservoir monitoring system outlined in this paper is derived from the system deployed at Coso.



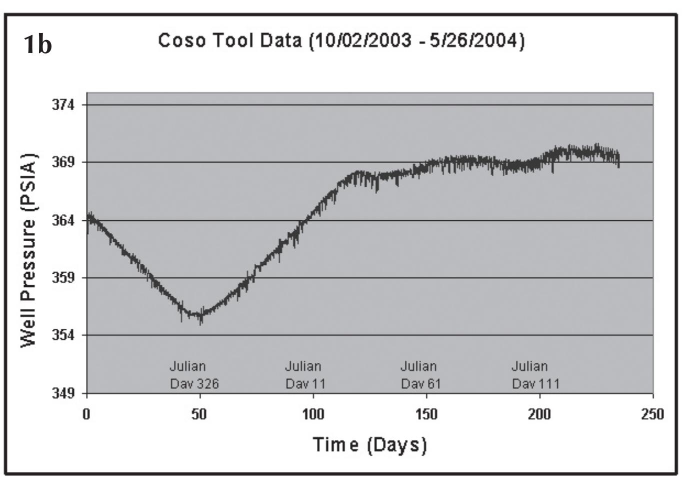


Figure 1. Temperature (1a) and pressure (1b) measurements made at the Coso Naval Test Range Well.

The charts shown in Figure 1(a) and 1(b) depict the temperature and pressure measurements we have made in this well thus far.

The reservoir monitoring system consists of the following subsystems: 1) downhole tool, 2) communication/power link to surface, 3) uphole data receiver/logger, 4) satellite transmitter, powered via a battery system charged by solar panels.

A Description of Each of these Subsystems:

Downhole Tool

With the addition of the Sandia designed ASIC (HT83SNL00), we were able to design and build a reservoir monitoring tool capable of sustained operation at 240°C. The tool utilizes a subset of the HT83SNL00 capabilities that include 3 bridge type measurements, 13 additional analog measurements, 2 precision frequency measurements, and 3 low resolution frequency measurements. We currently have a Quartzdyne pressure transducer and a RTD temperature sensor installed in the tool. We are making additional measurements such as downhole voltage to help monitor the status of the electronics. Quartzdyne, Inc. has performed extensive life testing to 225°C and is capable of resolving better than .008 psi and a temperature measurement better that .008°C. The tool was designed to enable additional sensors to be installed as they become available. This approach also lends itself to "customizing" the tool to meet a particular application without a complete redesign.

The tool is 7 feet long and less than two inches in diameter. The tool can be deployed using a standard logging cable or wired tubing.

The data is transmitted uphole using FSK (Frequency Shift Key) data encoding. The carrier frequency chosen for this tool is approximately 70kHz. This data transmission scheme is ideal for transmitting through long wires and has been used by Sandia for many years at wire lengths up to 15,000 feet (the length of our logging truck's cable), although not limited to this distance. The data is transmitted every 3 seconds. This rather lengthy time interval is needed for the Quartzdyne transducer. Since the Quartzdyne sensors are frequency based, sufficient gate time is needed to maximize the resolution of the pressure and temperature sensor. The acquisition time interval for the tool is determined based on the application and the sensors required.

Communication/Power Link

The communication/power link between the downhole tool and the uphole data receiver is a tubing assembly consisting of four 22-AWG wires packed into ¼ inch OD Stainless steel tubing. Teflon (TFE) insulation was used on the wires and as the insulating material between the wires and the tubing. The downhole hardware was designed to accept both a standard logging cable or wired tubing. Standard logging cable is considerably less expensive but was not chosen as the communication link due to the long-term deployment at high temperature. By using stainless steel tubing, a metal-to-metal seal is utilized throughout the downhole hardware package. While standard high temperature logging cable is rated for operation at temperatures up to 300°C, it has been our experience that relying on elastomer seals for long-term deployment can lead to seal integrity problems. This eventually leads to cablehead issues that require the downhole tool to be removed from the well and serviced.

Uphole Data Receiver/Logger

The uphole electronics consists of two elements. The first element is the uphole data receiver. It decodes the downhole data from the FSK encoded data scheme used to transmit the data uphole into a digital format compatible with the data logger. In this case, the data is decoded into a RS232 data format, which is compatible with most commercially available data loggers. The second element is the uphole data logger, which reads both the data from the downhole tool and any surface measurements that are required. The data logger chosen for this application is the Campbell Scientific Model CR10X. The data logger performs the following functions: 1) stores the downhole data to memory every 5 seconds, 2) makes additional surface data measurements, and 3) formats the data that will be transmitted via satellite for pseudo real-time display of the data.

The additional surface data includes the downhole tool current, downhole tool supply voltage, wellbore pressure measured at the surface, solar-charged battery status, and surface temperature. All of this data helps to diagnose the condition of the downhole monitoring system remotely. Of these additional measurements, the downhole tool current is the measurement that helps the most in determining the "health" of the downhole system. For example, if there is suddenly a large increase in current, a catastrophic failure is identified. In the past, these failures have been related to shorting capacitors or electrical feedthrough problems at the cablehead. We have tried to eliminate these two failure mechanisms by 1) using 200V, 200C capacitors for 5 - 10 volt circuits and 2) replacing the standard logging cable with a wired tubing solution designed with metal seals. A sudden reduction in current is normally the result of a failed connection, which usually causes the loss of data or a reduction in the tool's functionality. It is worth noting that a slight increasing drift in supply current is the normal result of IC degradation. The downhole reservoir monitoring tool has a 20,000 logic gate HT83SNL00 chip, an 8 bit microprocessor, 32,000 bytes of RAM and a host of analog circuits. When any transistor degrades, the level of leakage current normally goes up. However, the circuits may continue to run for a long time without noticeable loss of data or function. Thus, current will be our best detection method for tracking IC degradation.

Satellite Transmitter

The satellite transmitter enables a means for the data from the Downhole Monitoring System to be viewed remotely anywhere in the world. The satellite utilized for this system is one of NOAA's (National Oceanic and Atmospheric Administration) satellites namely the GOES (Geostationary Operational Environmental Satellite) satellite. Examples of the users of this satellite include the National Weather Service, Department of Defense, global research projects, Air and Ground Traffic Control, ship navigation, agriculture, and space services. Sandia's Geothermal department is now a contributor to this system by providing pseudo real-time data of a Geothermal well and making this data available to anyone with internet access. As stated earlier, the data in itself is important, and additionally, this system is a test bed for newly developed high temperature sensors, creating a testimonial for the reliability of tools designed with SOI components. The satellite transmitter chosen for this project is the Campbell Scientific Model HDR GOES.

Conclusions

The time is right to exploit the use of high temperature electronics based on SOI and SiC technology. Sandia has achieved a barefoot logging tool for accurate pressure and temperature (PT) measurements without heat-shielding. A natural progression from the PT Tool was the reservoir monitoring system. The benefit from this type of system is threefold. The data in itself is important and additionally, the system is a test bed for newly developed high temperature sensors and is a testimonial for the reliability of tools designed with new high-temperature electronic components and sensors.

Sandia is working to "seed" the geothermal service companies to excite new development. By providing an inexpensive learning kit to service companies, the time it takes to develop a high temperature tool is greatly reduced. This approach will help move this technology into the field more quickly and will in turn raise the industry standard on high temperature drilling and well logging.

Lab and field-testing is essential when developing high temperature tools. By lab and field-testing tools and components, pitfalls can be identified early and strategies can be made to eliminate them.

As more and more HT tools are successfully fielded, the need for HT electronics will increase. The proven reliability of SOI and SiC technologies has helped to spark ideas for many additional HT applications. The components that are developed for these applications will enhance the capabilities of all HT applications.

Acknowledgements

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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