Geothermal Power Plays

High Temperature Electronics for Downhole Environments

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SALES & MARKETING

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Agenda:

- Introduction
- Given
- Goals
- High Temperature
- Applications
- Focus – High Temperature Artificial Lift
- High Temperature Electronics for Downhole Environments
- HT Solutions
  - Components & Sub-Systems
  - Engineering Services & Turn-Key Systems
- Conclusion

Joule's Niche:

Joule is a contracted sales representative of high temperature suppliers. We represent suppliers of components, sub-systems, design and contract engineering services, specified to operate in high reliability or extreme temperature environments.

Our vertical market strategy and experience makes Joule a valued resource to both Customers, and Suppliers.

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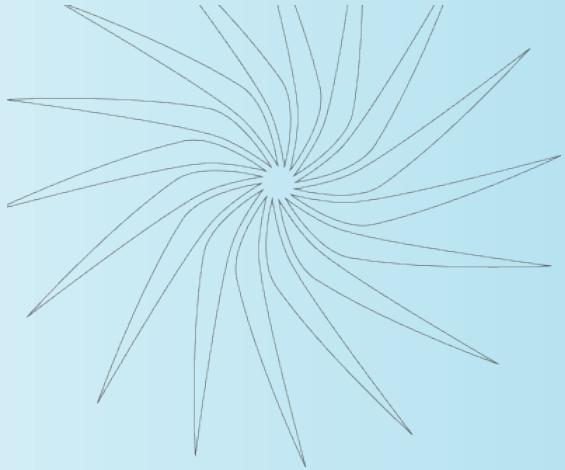
Markets Served:

Current Market Engagements:

- Oil and Gas
- Military and Aerospace
- Semiconductor
- Geothermal Energy



Emerging Target Markets :

- Military Automotive
- Solar and Wind Energy

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Geothermal Power Plays

High Temperature Electronics for Downhole Environments

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Given:

Geothermal drilling, formation evaluation, and downhole monitoring is the most challenging with hottest and hardest demanding conditions.

This environment severely limits the life and performance of electronic components, sub-systems, and turn-key designs.

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Given:

LEVELIZED COST OF ELECTRICITY
LCOE Formula

$$\mathrm{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

I_t = investment expenditures in the year t; M_t = O&M expenditures in the year t; F_t = fuel expenditures in the year

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Et = electricity generation in the year

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Presentation Goals:

- Provide an overview of electronic components, sub-systems, tools and engineering services available today for high temperature downhole applications.
- Specifically target increasing the rates of flow, and overall improvements in artificial lift.
- Identify companies / entities with specific high temperature interest and determine contacts to engage with.

High Temperature:

The definition of high temperature is application specific.

For our discussion today we will focus on:

Geothermal EGS

Typical 200˚C - 300˚C

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Applications

High Temperature Electronics for Downhole Environments

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High Temperature Downhole Disciplines:

Drilling and Measurement
Formation Evaluation
Intervention
Completions
Production

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Common DHT Applications for Components and Sub-systems:

- Energy Storage
- Actuation
- Power Conversion / Inversion
- Voltage Regulation
- Gate Drive / Motor Drive / Motor Control
- Data Acquisition / Communication / Storage
- Well Monitors
- Artificial Lift - ESP

EGS 230˚C Artificial Lift
(Currently not available)

A MIT panel in the “Future of Geothermal Energy” noted that it is critical to develop a production flow rate of 80 kg/sec at 200°C well head temperature to make EGS systems viable.

ONE kind of artificial lift appears applicable for geothermal EGS systems; Electrical Submersible Pumps (ESP)

- ESPs have higher potential for reaching EGS optimal production
- Biggest and highest temperature ESP should be used
- Conduct HALT and HT Aging to predict EOL

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High Temperature Electronics for Downhole Environments Applications

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High Temperature Silicon Components

- Some Silicon based devices may support operation to:
  - ~ 190 - 200˚C with appropriate high temperature packaging
- Tj and thermal shutdown are common limiting factors
- Die availability is usually limited
  - Minimum Order Quantities (MOQ) of wafers required
  - May be cost prohibitive for low volume usage
- Die requires HT packaging
- Silicon based components should be used if functionality cannot be found in SOI, SiC or GaN technologies
  - HT Characterization & Aging is required for critical mission profiles
- Recommend - HT Ceramic Packaging / Flask Technology
  - Contracting experienced HT Design Teams

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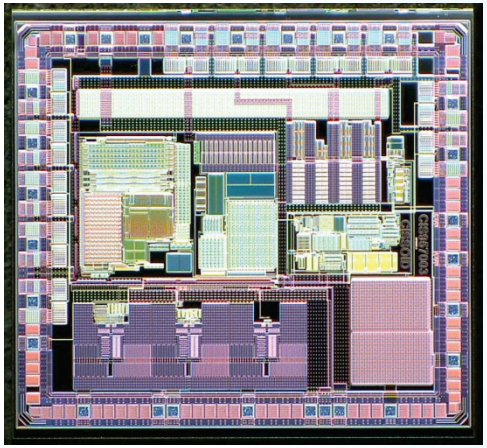
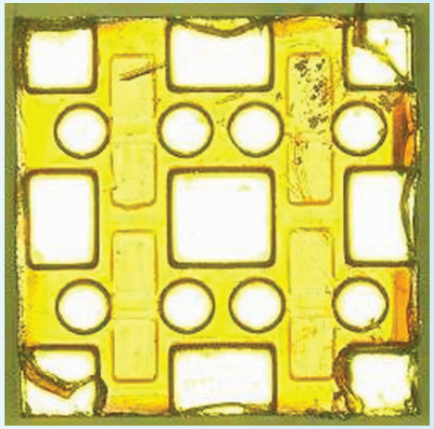
HT Semiconductors which can be used for Geothermal Applications



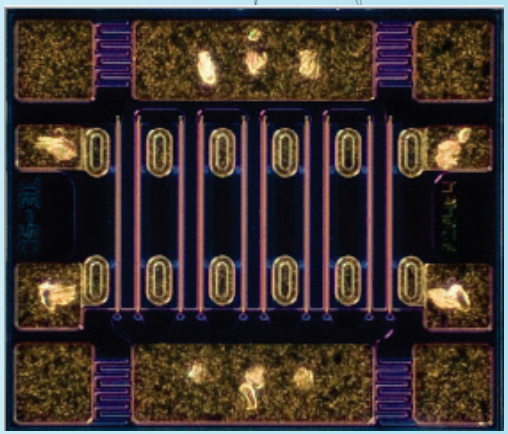
HTSOI

High temperature silicon on insulator devices rated to 230 °C and operable to 300 °C. Devices include Gate Drive, MOSFETS, 555 timers, voltage regulators, microcontrollers, op-amps, logic, ADCs, etc…
AVAILIABLE TODAY



SiC

Silicon Carbide devices have been field tested to temperatures in excess of 550 °C, with some literature reporting transistor operation up to 650 °C, and SiC ICs have been demonstrated
AVAILABLE TODAY



GaN

Gallium Nitride devices are mainly discrete transistors, which have been shown to operate up to 600 °C, with a theoretical operating temperature higher than SiC

NEW TECHNOLOGY

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X-Rel Semiconductor

SOI Reliability Assessment

> Devices are set at still 250°C (case temperature) on an application board with dynamic bias conditions.

> Permanent operation monitoring is carried out, though only total failure is detected here.

> Parts are pulled out of the aging fixture at given schedule to be tested according to the standard test program at 25°C and 220°C. Pull Schedule is: once every 4wk. Results for each device are logged to show any possible drift.

> Two golden (not aged) parts are used to monitor test fixture dependence.

> Over 100,000 Hours at 250C for some devices to date

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High Temp Components:

EVANS CAPACITOR 200°C
>High Temperature High Energy Hybrid Tantalum Capacitors

APEI 225°C
>Silicon Carbide MOSFETS and GaN Power Modules
>H Bridge, Motor Driver and Gate Drive Solutions

SPJ Thick Film RESISTORS 300°C
>High Temperature, High Precision Wire Wound and Thick Film

UNITED SILICON CARBIDE 260°C
>High Temperature, Highly Efficient Diodes, JFETs and Cascode Switches

VECTRON INTERNATIONAL 230°C
>High Temperature Crystals and Oscillators

VANGUARD ELECTRONICS 220°C
> High Temperature Magnetics - Transformers, Inductors & Chokes

X-REL SEMICONDUCTOR 230°C
>High Temperature, Power Regulation, PWM and DC to DC Converters
>High temperature Gate Driver chipsets

CRITERIA LABS HT DIE PACAKGING 230°C
>High Temperature packaging / Component Characterization & Aging

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High Temperature Sub-Systems And Design Services

Very Little “Off the Shelf” solutions exist above 175˚C

- IR SOI DC to DC Power Modules
- APEI Gate Driver, Motor Driver & Power Conversion

200˚C + solutions are application specific.

- For high temperature contract engineering we need an agreed upon specific Statement of Work (SOW), complete with mission/test profile and a prototype acceptance document to begin design.

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High Temp Solutions >175C

PERMAWORKS* 300°C

> Reservoir Testing and Monitoring {PW-PT535A} High Temperature, High Reliability tool designed for and delivers reservoir stimulation and well shut in testing visibility.

FASTCAP ASYSTEMS* 150°/200°C

> High Temperature Ultra Capacitor
> High Temperature Battery Systems

TI 210°C

> MCU, OP Amps, Power Analog, Signal Conversion

ADI 200°C

> OP Amps, Signal Conversion

REL-CHIP* 300°C

> High Temperature 32-Bit MCU, Memory

CREE / ROHM / INFINEON* 175°C

> High Temperature, SiC Diodes and MOSFETs

VECTRON INTERNATIONAL 180°C

> Real-time Clock Module

HDA* 200°C

> High Temperature Memory

CRITERIA LABS HT DIE PACAKGING 230°C

> SOI/ SiC Motor Driver & DC to DC

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Joule Design Services:

CAPACITOR MODULES 200°C
>HP/HT High Energy Hybrid Tantalum Capacitors Modules

POWER SUPPLIES 200°C
>Low and High Voltage Power Supplies 1W – 100KW

SOI DATA ACQUSITION 225°C
>High Pressure, Strain and High Temperature Data Acquisition
>Position Sensing

SILICON CARBIDE POWER MODULES 260°C
>High Temperature, High Power Energy Conversion, Gate Driver and Motor Drivers

REAL-TIME CLOCK MODULES 180°C

CUSTOM MAGNETICS 220°C

HIGH TEMPERATURE CHARACTERIZATION/AGING 230°C

DIE, MCM AND HYBRID PACKAGING 240°C

DOWNHOLE & SURFACE ELECTRICAL AND MECHANICAL ENGINEERING SERVICES -40°C to 230°C
>Application Specific Design Services

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Conclusion
Cost-competitive energy requires technology development

- Investment in High Temperature Research & Development
  - DoD , DoE , DoT & NASA
  - Continued support of National Laboratories
- Private initiative creating innovation in technologies
  - Government and Corporate sponsorships
- Production process improvements – ESP
- Utilization of HT downhole technologies and experience
- HT Characterization, aging and deployment

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Thank you.

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Fueling Next Generation Design,
Delivering Innovative High Temp Solutions.