6.1 Automotive

6.1.1 Combustion Engines

Combustion engines are increasingly reliant on under-the-hood electronics to improve fuel efficiency. Up to now, car makers have taken pains to place the electronics so that their operating temperature does not exceed 125°C.

Figure 6.1 indicates the maximum temperatures experienced in the engine.

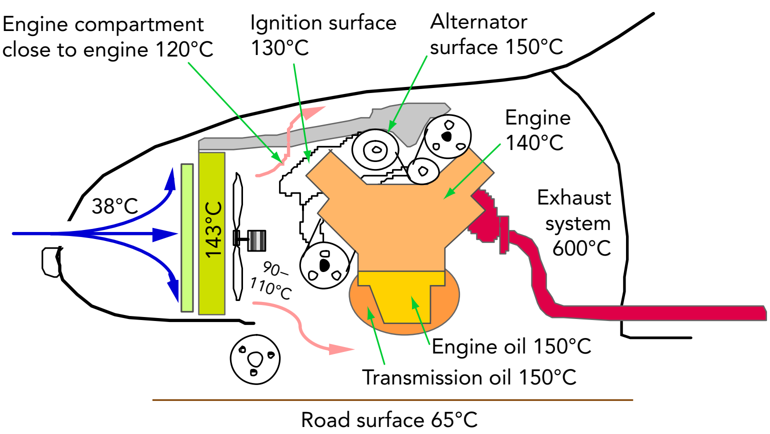

Figure 6.1: **Thermal environment of a car engine**

Benefits of SiC electronics

SiC electronics could be placed anywhere in the engine, alleviating design constraints and reducing the number of wires and connections (which in turn would improve the reliability of the car). Given the extreme cost sensitivity in the automotive industry, the price of SiC components would be a major obstacle to their use in the near-term, even assuming they can be reliably produced in volume.

6.1.2 Exhaust Gas Sensors & Air-quality Sensors

The automotive industry in the US and particularly in Europe is however interested in gas sensors to monitor the exhaust process to improve efficiency and lower pollution, and also potentially for cabin air quality monitoring. Cabin sensors automatically control the operation of the fresh air vents. Mercedes and BMW have been quick to adopt such devices, which are typically based on inexpensive ($5–10) micromachined silicon MOS solutions. In 2005, cabin sensors are expected to make further in-roads into mid-class cars supplied by Saab, VW and Volvo, and will be found in all new European cars by 2010.

In the more extreme environment of the exhaust stream, the Lambda sonde is used as an in-line sensor to detect remnant oxygen in the exhaust gas. The Lambda sonde probe is typically ZrO_2 or TiO_2. The sonde is part of a feedback loop to an injection system and ensures the correct fuel/air ratio, reducing pollution and fuel consumption. Originally developed by Bosch, Lambda sondes are now offered by several other vendors.

European emission regulations (EURO 3/4/5) will dictate the use of such probes in all new European cars. More expensive systems are also employed by workshops to monitor a range of emission gases (NO_2, CO, CO_2, HC, O_2, NO, etc).

Also driving interest in SiC is an application for on-board monitoring of NO_x (i.e. NO and NO_2), and for ammonia sensors used with selective catalytic reduction (SCR) of NO_x by ammonia or urea in diesel exhausts. SCR-based sensors are expected to present a large market opportunity for SiC when new emission regulations come into force in Europe in 2007. Because flue gases from boilers are very similar to diesel emissions, there is also interest from the power industry.

SiC Sensors

SiC devices are sensitive to hydrogen, CO, hydrocarbons and NO_x. The sensor employs platinum, which is used as a catalytic metal-gate Schottky barrier. In the case of hydrogen, the metal cracks the gas molecule into atomic hydrogen, which then diffuses into the device. The subsequent creation of a polarized layer at the interface lowers the energy barrier between the metal and semiconductor junction, which can be measured.

Schottky diode sensors are being investigated by Linköping University (which is also developing SiC FETs), ACREO and AppliedSensor (a spin-off from Linköping University and the University of Tübingen) together with automotive manufacturers. Applied Sensor is one of the few European companies concentrating on a SiC solution for this application.

Nippon Steel, Matsushita Electric Industrial, Sanyo Electric and Mitsubishi Electric have also been collaborating with several Japanese universities to develop SiC gas sensors to control the combustion chamber. The project was supported by the Japanese New Energy and industrial technology Development Organisation

(NEDO).

Other research groups working on SiC include NASA Glenn Research Center, Case Western University and for GaN, the Walter Schottky Institute in Munich, although SiC is more advanced in terms of processing.

Requirements

A SiC ammonia sensor can be used to monitor NH_3 in diesel exhaust following its mixing with NO_x to form water and nitrogen at 300°C–450°C, with peaks occurring at 500°C–600°C. This temperature range is experienced downstream in the exhaust, and subsequent devices further upstream will operate from 600°C–900°Cand require advanced packaging. The requirements on these sensors are:

- reaction measurement speed of the order of milliseconds
- high reliability
- cost of $30–$100
- 5–10 year service life.

Markets

Exhaust gas sensors represents a long-term opportunity for SiC but have no immediate impact on the overall market for SiC components. SiC gas sensors are still a long way from commercialization and devices are not expected within the next five years.

6.1.3 Power Conversion & Electrical Steering

The transition from a 14.4 V bus (12 V battery) to a 42 V (36 V battery) provides an exceptional opportunity for SiC in auto electrical systems. The first transition in bus voltage (6 V to 14 V) took place in the 1950s. New systems under development that will exploit the 42 V bus include steer-by-wire (replacing the hydraulic power steering pump with a polyphase AC motor), brake-by-wire, and electric throttle valve control. The most promising applications for SiC are electromechanical valves, electric active suspension and the integrated starter/alternator (having only one brushless DC motor or switched-reluctance motor to perform both functions).

In 42 V systems, the components have to be rated for 58 V operation to account for the load dump transient [1]

System	Peak load	Average
Water pump	300 W	300 W
Engine cooling fan	800 W	300 W
Power steering (all elec.)	1000 W	100 W
Heated windshield	2500 W	200 W
Catalytic converter pre-heat	3000 W	60 W
Active suspension	12000 W	360 W
Comm./navigation		100 W
Total		2220 W

Table 6.3: **Electrical loads found on a car in 2005** *(source: Infineon)*

Benefits of SiC

SiC electronics could be placed anywhere in the car, independent of the ambient spot temperature. The requirements of cooling are removed, which would decrease the weight and reduce the size of the systems.

SOI is a very strong candidate for automotive power electronics, since the temperature as well as power ranges required are not as extreme as in the case of space applications, for example.

Requirements

The electrical performance required for any power component linked to the 42 V bus are easily met by SiC. On the other hand, price is a determining factor for automotive components and the cost of SiC components (assuming they could be mass-produced) is still several orders too high.

Markets

Electrical sterring represents a long-term opportunity for SiC but have no immediate impact on the overall market for SiC components. SiC components are still too immature and unreliable whereas SOI has emerged as a cheap and reliable technology.

[1] The load dump transient occurs when a fully loaded alternator has its load disconnected. This happens when the battery is being charged at its maximum rate and a connector comes loose.

Place	Max. temperature	Electronics
Passenger compartment	85°C	Displays
Under the hood	150°C	Control for power train, engine, transmission
Engine	200°C	Electronic Control Unit (ECU), Train Control Unit (TCU)
Wheel	300°C	Brake-by-wire Steer-by-wire
Combustion chamber	500°C	Pressure sensors
Exhaust pipe	800°C	Gas sensors

Table 6.4: **Temperature hotspots in a car**

Suppliers

Denso aims to have developed a SiC MOSFET in 2007 and intends to introduce SiC inverters by 2010. Nissan is collaborating with SemiSouth Laboratories to develop a SiC power chip by 2011.