Trends of Automotive Electronics and Material Needs

Toshiaki Ishii

1st Electronic Device Design Dept. , Automotive systems, Hitachi, Ltd.

ABSTRACT

Vehicles to realize low emission, safety driving and comfortable compartments are increasingly required. For environment, the market of hybrid vehicles is expanding contributing to reducing CO_2 emission and fuel consumption. To materialize more safety vehicles, the future active safety system is being developed. Systems for next generation vehicles are electrically-powered and electronically-controlled, so the system require many electronics such as sensing devices, electronically control components, a inverter and control units. Those electronic components should be not only small, lightweight and low cost but also highly reliable. The higher power density of the component due to smaller packaging are required technologies of high heat dissipation and heat resistance. We place expectations on materials technology, especially organic materials as a break-through technology for automotive electronics. Novel materials and approaches for automotive electronics are presented.

1. AUTOMOTIVE SYSTEM TRENDS

Safety, comfort and eco-friendly cars are demanded. Although victims of car accidents have been decreasing since the regulation of seat belt started, the number of accidents have still been at high level. To improve the safety of vehicles, active safety systems are expected to prevent car accidents. In addition, in terms of the environment, highly-efficient engine control systems have being developed contributing to reduce fuel consumption and to eliminate exhaust gas contents. Moreover, hybrid vehicles have become popular because of their low gas emission. Under the circumstances, the number of car electronic components are increasing. In the future, the increasing rate is expected to accelerate to develop the next generation vehicles which may required more advanced electrical-powering and electronic-controlling technologies.

An example of the active safety systems is schematically represented in Fig. 1. This system has a camera and radar mounted on the car front to detect obstacles obtaining their data to compute how to clear the obstacles and control the vehicle stability by operating the steering, suspension and brake. A more advanced car information system would communicate traffic information, car driving information, and car malfunction information through the network to a system existing out of the car, aiming to more comfortable and safety driving. This type of systems which electrically control an electric steering, suspension, and brake are called as x-by-wire systems. The systems would mainly consist of electric components resulting in lighter weight and lower energy consumption than those of conventional hydraulically-operated systems. On the other hand, such electric /electronic components of x-by-wire systems are required to be mounted in harsh environments such as on/in engines with high temperatures, high vibration and highly corrosive conditions which may damage the components.

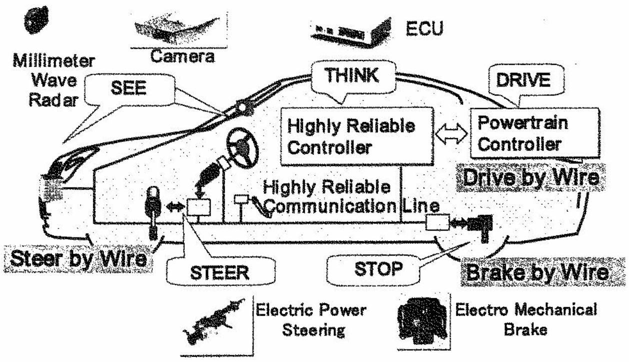

Fig. 1 Active Safety System

On the other hand, in the field of eco-friendly vehicles, the low fuel consumption technology with electronic engine control and the catalyst technology for gas emission have been significantly developed. In recent years, hybrid electric vehicles (HEV) have been very popular due to their low CO2 emission and fuel consumption. The key components of HEVs are a small motor, high capacity battery and inverter system.

As mentioned above, the advanced electronic control systems are necessary for the next generation vehicles. These systems are required to have a small size and high capacity. Such requirements are likely to increase their power densities. Also, the reliability of such a system must be higher than those of consumer products including personal computers or mobile phones.

The material technology has being played a very important role to keep the reliability of electronic components for automotive systems. In the next section, trends of automotive electronics and their requirements to the material technology are summarized showing some examples of material developments.

2. REQUIREMENTS of AUTOMOTIVE ELECTRONICS

An overview of a typical electronic control unit (ECU), an engine control unit, is shown in Fig.2. This ECU controls an engine to keep its efficient driving by computing optimum fuel flow rates and ignition timings with data such as air flow rates and speeds sent from the gas pedal. The structure of the ECU is on a printed

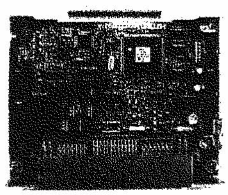
Fig. 2 Over view of Electronic Control Unit

wiring board connecting LSIs and passive components with pads by soldering. Other ECUs controlling transmissions or steerings also have almost same functions and structures.

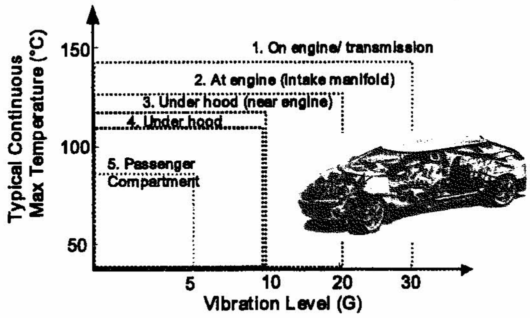

Fig. 3 Temerature and vibration level in various place of car

Fig.3 shows environmental conditions focusing on temperatures and vibration of ECU mounting places in a car. Temperatures and vibration applied to an ECU are usually mild when it is placed in a compartment. However, the conditions may be harsher if it placed in an engine room. The number of ECUs mounted in engine rooms would be increasing as the x-by-wire technology will develop. Development efforts should focus on improving the reliability of ECUs under higher temperatures above 150C° and vibration levels over 30G [1].

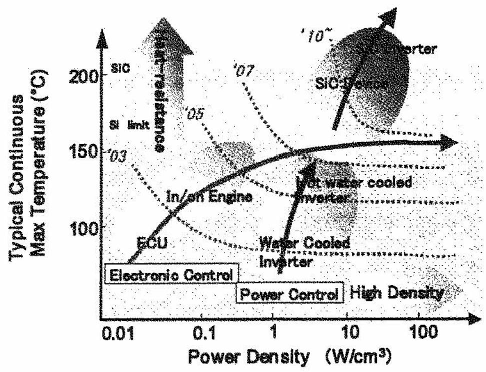

Fig. 4 Power density treds in car electronics

The continuous temperature range of automotive electronics is plotted against power density in Fig. 4. The typical continuous temperature of ECUs is increasing with growing demands for smaller and higher power packaging. The temperature range will close to almost the limit for silicon semiconductor devices. An inverter system for HEVs, which has its own coolant system to dissipate a heat from their power modules, also increases power density and typical continuous temperature due to small and low cost packaging. Therefore high heat dissipation technology and high thermal resistant materials are needed. Silicon carbide is expected to be applied to high efficiency devices in the next generation. The devices are required to operate at high temperatures over 200 C delivering high performances. Consequently, the packaging technology to achieve high thermal resistance is strongly required.

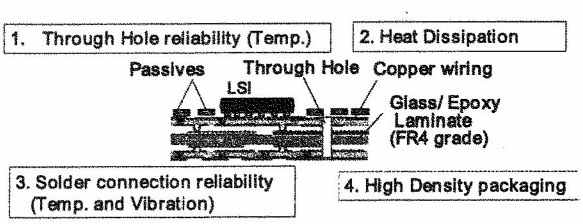

Fig. 5 Cross sectional view of Electronic Control Unit

A cross sectional view of a general ECU is shown in Fig. 5. Several electronic components are connected by soldering with a printed wiring board (PWB) composed of grass fibers and epoxy resin. The PWB is mounted in a metal or plastic case. Requirements for the packaging technology for such structure are as follow; (1) through hole reliability, (2) efficiency of heat dissipation, (3) reliability of solder connection, and (4) high density packaging. As shown in Fig. 3 and 4, because automotive electronics need high power density packaging to tolerate high temperatures and vibration conditions, advanced material technologies have been expected to respond to such demands.

3. MATERIAL NEEDS for NEXT GENERATION VEHICLES

Table 1 summarizes material needs for the next generation vehicles. At first, in terms of the global environment, high thermal conductivity materials are required for heat dissipation of HEV power modules and ECU. From the viewpoint of safety , low thermal coefficient materials are demanded for electronic-control systems such as an x-by-wire controller, in order to maintain the connection reliability of ECU packaging under harsh environments (high temp. and high vibration level). Finally, in view of the comfort , high dielectric material for embedded passive technology are demanded to increase the packaging density of car information systems.

Table 1 Materials Needs for Car Electronic Packaging

Social Needs	Vehicle System	Component Requirement	Materials needs	Approach
Environment	Electric powertrain (HEV, EV)	High thermal Resistant	High thermal stability and conductivity	High Thermal Conductive Resin
Safety	Drive control System X by Wire	High thermal and vibration resistant	Low Thermal Expansion	Epoxy-Silicon Hybrid Resin; Resin Molded ECU
Comfort	Navigation Telematics Entertainment	High density packaging (Embedded passive)	High/Low dielectric materials	Polymer-Ceramics Nanocomposite

Actual development of packaging and material technologies are illustrated in the next section.

(1) RESIN MOLDING TECHNOLOGY

A solder connection on a PWB may suffer stress by temperature changes and coefficient of thermal expansion (CTE) mismatch between the connected electronic component and the PWB. The destruction of a solder joint occurs when a large stress is repeatedly applied on the joint causing its strain An effective method to reduce such

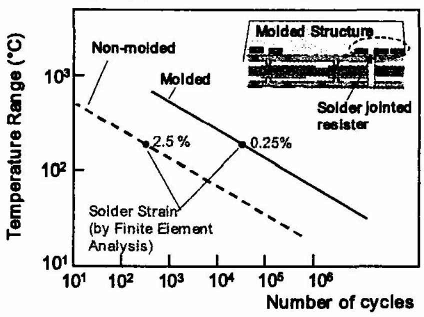

Fig. 6 Reliability of Solder Joints of Resister

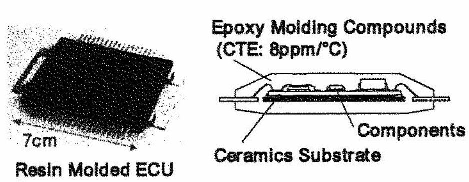

Fig. 7 Resin Molded ECU

stress is to mold resin around the solder joint. Fig. 6 shows solder strain changes between resin-molded and un-molded structures. The strain of the resin-molded structure was one tenth reduced than that of the un-molded structure. The connection life of the resin-molded was about ten times longer than that of un-molded structure. It would be obvious that the molded structure has also strong durability to vibration. ECUs applying this method have substrates entirely molded with low CTE epoxy molding compounds. One of the features of these low CTE compounds is high density of silica loaded into epoxy resin to in order to lower the CTE (Fig. 7)[2].

(2) EPOXY-SILICON HYBRID RESIN

Epoxy-silicon hybrid resin has been developed to enhance thermal stability and reduce CTE of substrates or EMCs [3]. The resin consists of nano-scale silicon particles and epoxy resin. The nano-scale particles restrict cross-linked structures of epoxy resin matrixes to acieve low CTE and high glass transition temperature (Fig.8). The temperature dependence of elastic modulus and CTE is shown in Fig. 9. The result of the temperature dependence of elastic modulus does not make clear the glass transition temperature (Tg) of the hybrid resin. The hybrid resin gives higher elestic modulus and lower CTE than that of conventional resin at high temperatures (above conventional resin Tg). With this hybrid resin, a lamination was fabricated to evaluate its characteristics. The lamination properties are listed in

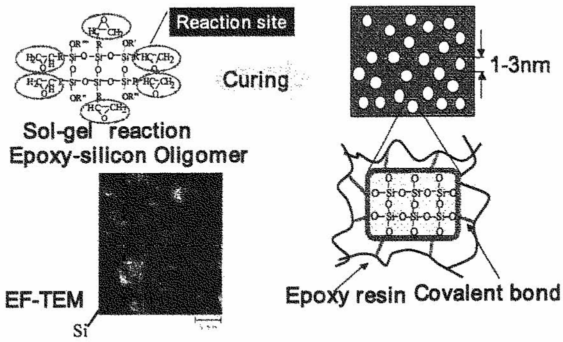

Fig. 8 Concept of Epoxy-Silicone Hybrid resin

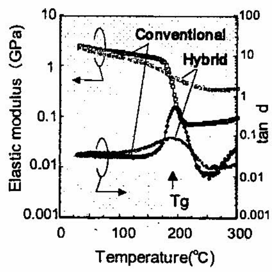

Fig. 9.1 Temperature dependency of elastic modulus

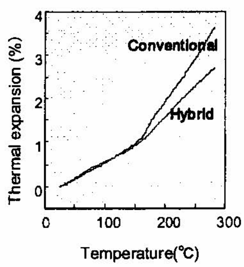

Fig. 9.2 Temperature dependency of thermal expansion

Table 2 General Properties of Laminate

Property	Condition	Hybrid lam.	Epoxy (FR-5)
Elastic modulus (GPa)	25°C	22	22
	260°C	20	9
Grass transition temperature (°C)	DMA	non	206
Thermal expansion coefficient (ppm/K)	50-100°C	43	41
	200-250°C	162	300
Peel strength (kN/m)	25°C	1.4	1.4
Dielectric constant	1MHz	5.0	4.8
Dissipation factor	1MHz	0.02	0.02
Water absorption (wt%)	PCT-3hr	0.8	0.6

Table 2. This lamination was proved to have a thermal stability comparable with the high thermal grade of FR5 and a low CTE.

(3) HIGH THERMAL CONDUCTIVE RESIN

Organic materials have been a bottleneck of low thermal conductivity of electronic packaging [4][5]. Hence improvement in thermal conductivity is strongly demanded. One of conventional methods to increase the thermal conductivity of such a composite is to increase the amount of a filler which has a highr thermal conductivity than that of the organic resin. This high filler loading technique causes some detects of the resin such as viscosity increasing or high brittleness. Under the circumstances, a method to enhance the thermal conductivity of a resin matrix itself has been studied. A concept of the method is shown in Fig. 10. Mesogen units are introduced into epoxy molecules. The units form an ordered structure during the curing process of the epoxy resin. The ordered structure is considered to be smaller phonons scattering in amorphous structures achieving a high thermal conductivity of the cured epoxy resin. The thermal conductivity was confirmed to be five time larger than that of a conventional epoxy resin (Fig. 11). Fig. 12 indicates the mesophase and microphase of the ordered structure observed by atomic microscope and transmission electron microscope. The structure consists of domains with several microns in which mesogens form an ordered structure. The scale of the structure is small though, it gives isotropic mechanical properties to the resin. Fig. 13 shows a thermal conductivity of a composite containing this resin. It was confirmed that the increase in resin thermal

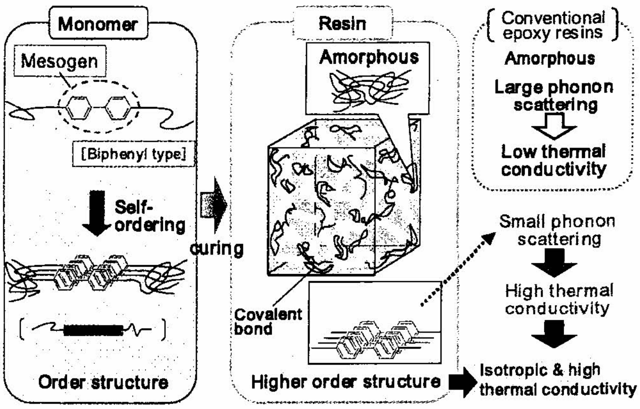

Fig. 10 Concept of Thermal Conductive

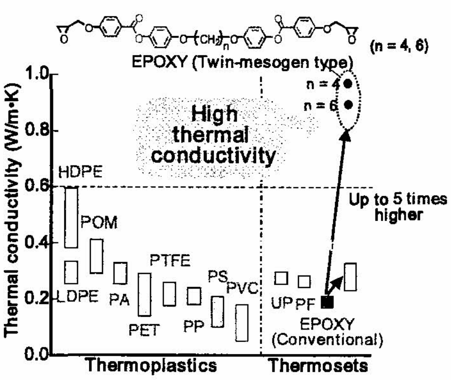

Fig. 11 Thermal conductivities of various resins

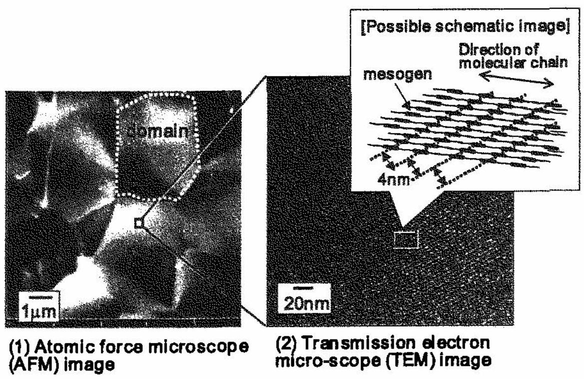

Fig. 12 Nanoscopic and mesoscopic images of high-order structures

conductivity largely enhances the composite thermal conductivity. The composite is expected to address thermal problems in electronic packaging.

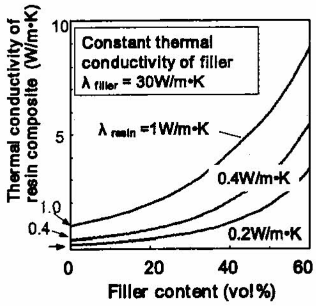

Fig. 13 Filler content dependence of thermal conductivities of resin composites.

(4) POLYMER-CERAMICS NANO-COMPOSITE

High dielectric materials for passive devices embedded in a substrate has been developed[6]. The concept is shown in Fig. 14. One of these materials consists of TiBa, hyper-branched methalonaphthalocyanine (hy-CN)[7] and a blended polymer. TiBa that gives high dielectric property is a core material and covered with hy-CN to increase the affinity with the polymer to mix with it. A blend of high thermal stable polyamide and bismaleimide is used as the polymer. This composite exhibits the relative dielectric constant of 80 at 1MHz (Fig.10). Embedded capacitors in a 6-layers printed wiring

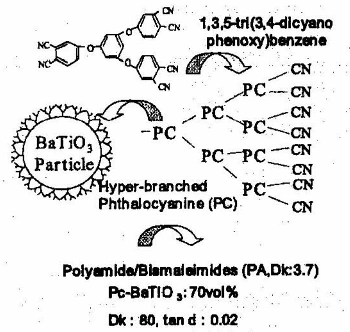

Fig. 14 Concept of High dielectric materials

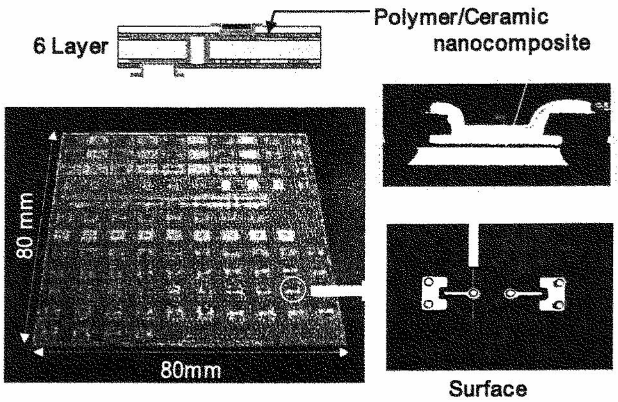

Fig. 15 6-layer Wiring substrate with embedded capaciter

Table 3 Dielectric and general properties of substrate

Property		Pc-BTO : 70vol%
Thickness	—	9 μm
Peel strength	A	0.7 kN/m
Dielectric constant	1 MHz	82
tan δ	1 MHz	0.02
Specific Capacitance	1 MHz	8 nF/cm^2
Break down V	—	> 200V
Leak current	at 10 V	< 10 $^{-10}$A/cm^2
Solder float	260 ℃	> 300 s
Electrical migration	RH85%/85 ℃ /35V	> 800 hrs

substrate was fabricated with the composite. A cross sectional view and overview of the PWB is shown in Fig. 15. Poperties of the substrate are summarized in Table 3. The capacitor characteristic value of 8nF/cm^2 was obtained.

4. SUMMARY

(1) Automotive systems realize environmental- friendly vehicles with great safety, comfort, and with communication ability with people, roads & society.

(2) The electric powertrain systems (HEV, EV) and electronic control systems (X-By-Wire) will be widely applied to the next generation vehicles.

(3) Electronic components will be exposed to high temperatures and harsh environments due to higher power density. High thermal stability and efficient thermal management should be achieved.

(4) Materials with high heat resistance and high thermal conductive properties are expected to be developed for electronic packaging.

5. REFERENCE

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