Metal and Ceramics Technology 2004 : Review & Forecast

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From the IT field and the PT field, advanced and highly specialized materials are increasingly required. Especially, specialized requirements for metals and ceramics should be spread these characteristics on the basis of new materials and nanotechnology. In this paper, some advanced metals and ceramics regarding to generation changes in process materials, new dielectrics for the digital devices field, compound semiconductors for the power devices field, and materials for the optoelectronics field will be reviewed and forecasted.

Keywords : superconductor, dielectric, carbon nano-tube, DRAM, semiconductor laser, LD, solar cell, GaN-surface emitting laser, high-density mounting, single flux quantum, power electronics, SiC-MOSFET, photonic-crystal, quantum computer

We are faced with changing technology generations and contributing to strengthen the Japanese industrial competitiveness. Metal and ceramics are significant and indispensable materials for electromechanics, electronics and optoelectronics. For the sustainable development in Japan, the electronic and electric industries should play a key role in keeping international market share of about 10% or more. This means that metal and ceramics should continue to do their share in advancing basis of the Information Technology (IT) and the Power Technology (PT) as shown in Fig. 1.

1. Generation Changes in Process Materials

For the indispensable metal and ceramics to IT industries and PT industries, there are two kinds of the electric electronic materials, solid materials and gas materials. These materials will be defined as process materials or constitution materials for the digital devices, the power devices and the optoelectronics.

Fig. 1. Indispensable metal and ceramics to IT industries and PT industries

Although the materials are developed mutually, solid metal and ceramics materials of them will be reviewed and forecasted here.

Now we often hear in a post silicon generation. It is sure that as shown in Fig. 2 the electric electronic materials promptly change in the generations. Especially metal and ceramics should be considered for changing various needs, advancing to higher functions and extending to the global business area. Namely, the Si-wafer become 250mm to larger 300mm in diameter or one with the Silicon on Insulator (SOI) for the electronic devices such as a Dynamic Random Access Memory (DRAM), a Large Scale IC (LSI), the solar cell etc. Furthermore, these Si-based devices have changed to another compound semiconductors such as GaAs-, GaN-, SiC- and diamond-based devices for a Light Emitting Diode (LED), a Light Amplification by Stimulated Emission of Radiation Diode (LD), a photo-diode, a power inverter, a surface emitting laser, an advanced solar cell etc. Especially, a GaN-LED has suggested to come a new generation in the display devices. On the other hand, metallic transmission and metallization materials are changing aluminum to copper or copper insulated with various permittivity. Furthermore, the optical fiber changes the ordinary silicon-based fiber to an advanced high-performed one

Fig. 2. Generation changes in process materials

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such as an Er-doped fiber for a Wavelength Division Multiplexing (WDM).

2. New Dielectrics for the Digital Devices Field

The LSI's technology will face on a breakthrough in materials and fabrication technologies for advancing to higher functions.

Now the technology generation, which is defined by the half-pitch length of DRAM metallization, has soon graduated from 130nm, and will become 90nm into 65nm. For example, the Advanced Semiconductors through the Collaborative Achievement (ASUKA) project has set into operation to develop the System on Chip (SOC) with lower power consumption as a new mount technology for the 65nm generation in 2005.

Furthermore, for the 45nm generation, higher functions and lower power consumptions will be required by some technology breakthroughs. For instance, ultra-fine nano-technologies in sizing a Complementary Metal Oxide Semiconductor (CMOS) transistor and an application of gate insulation films with high-k (permittivity) and copper metallizations with low-k for interlayer insulation should be indispensable. In fact, the Millennium Research for Advanced Information Technology (MIRAI) project, which was planned for seven years from 2001 to 2007, has been undergone, and proposed a new gate insulator of HfO_2 with a higher relative dielectric constant of $k=23$ than $k=4$ of SiO_2 and an insulated copper wire with a porous SiO_2 having a lower relative dielectric constant of $k=1.5$ than that of the present poreless SiO_2 . Further technology escalations have been done in an application of carbon nano-tube as a beer material to the multiple-layer mounting for high-frequency devices for an advanced LSI.

Therefore, relating to technically fabricable limitations of a heat generation and a tight metallization in the silicon-based semiconductor devices to be at about 100GHz, an advanced switching circuit operation at 100GHz or more will be charged with developing the Single Flux Quantum (SFQ) circuits. In the Superconductors Network Device project, circuit designs and fabrication processings already have been carried with for the superconducting SFQ integrated circuits using the metallic niobium and the oxide superconductors YBCO.

Furthermore, in order to achieve shorter calculation time, a challengeable approach for developing the quantum computer, in which the algorithm will be essentially different from the current digital computers, has been carried out. On behalf of the quantum computer, the solid superconducting quantum bits and semiconducting quantum dot bits are promising extremely.

3. Compound Semiconductors for the Power Devices Field

The SiC semiconductors will be referred to the ordinary Si-based semiconductors for the power electronic devices.

The power electronic devices are important components as well as the Si-based LSI devices in the IT field, for the power source or the uninterruptible power supply (UPS) of the computers and the communication instruments. In the PT field, the power devices are also significant components such as the inverter for home electric apparatus, electric equipment for automobiles, motors for train, rolling equipment in ironworks, and AD/DC converters in substations.

Now, the Si-based semiconductors are applied mostly to the

Table 1. Comparison of material parameters

Item	Si	SiC	GaN
Band gap (eV)	1.12	3.2	3.39
Degree of electron transfer (cm^2/Vs)	1500	900	900
Electron saturation speed (cm/s)	1.0×10^7	2.7×10^7	2.17×10^7
Breakdown field (MN/cm)	0.3	3.5	2.0
Thermal conductivity (W/cm C)	1.5	4.9	1.3

power semiconductor elements. There are many kinds of power devices called Thyristor, a Gate Turn-Off Thyristor (GTO), an Insulated Gate Bipolar Transistor (IGBT), a Metal-oxide Semiconductor Field Effect Transistor (MOSFET) and so on. Recently, the design of the power follows behind about ten years that of the semiconductor memory. Then, the design rule of the power device is closed gradually to a theoretical on-resistance value of 0.1 ohm cm^2 in the MOSFET devices.

On the other hand, for the power electronic devices a requirement such as an Intelligent Power Module (IPM), in which power semiconductor elements, gate drive circuit, sensors, the Micro Processing Unit (MPU), etc are integrated in an assembly package, is closed up. For this need, smaller size of the power devices and a lower power consumptions in system level are required. As a breakthrough material, the SiC having some promising properties as shown in Table 1 is expected in the name of the present Si-based devices. These parameters were reported by the New Energy and Industrial Technology Development Organization (NEDO) project, developing an ultra low power consumption device technology.

In the case of SiC- MOSFET, four figures show as follows: (1) a thickness of the device is shorten by 1/10 times because of three times energy gap and ten times breakdown electric field, (2) on-resistance, corresponding to the operation losses of the device alone, is reduced by 1/300 times, (3) total switching losses in the system level are lowered by 1/3 times because of large carrier numbers, and (4) power consumptions are reduced furthermore for using a new Super Junction (SJ) structure. Although the SiC single crystal having 4 inches in diameter has been grown by a separate-sublimation method, if the SiC power electronic devices are realized, they will greatly contribute through use for the power supply, the UPS, the inverters, and AD/DC convertes to significantly effective use of electric energy and reduction of the CO_2 emission.

On the other hand, the diamond semiconductor will be promising material as an ultimately high-power and a high-frequency device for the communications satellite, the lader and so on.

4. Materials for the Optoelectronics Field

The optical devaices, blue light emitting lasers, portable instruments etc. have been attracted attention on behalf of the high speed and large transmission capacity such as a Tbps transmission system in the optical communications, the compactness in the portable or wearable instruments such as the portable phones and the wrist watches with the solar cell having high conversion efficiency. Then, various kinds of high-performed materials and module packages such as a System in Package

(SIP) should be required widely for the optical communications field.

The access network in the optical communications has been developed upto large capacities of some 100Mbps with a generation change transmission wires or cables to an Asymmetric Digital Subscribe Line (ADSL), a Fiber to the Home (FTTH) and boarbands. As a result, the backbone network having ultra high speed and huge transmission capacity, and development of ultra high speed optoelectronic devices are required. Already, the WDM using 1480nm class optical amplifier with In-Ga-As-P based semiconductor LASER and erbium-dopped optical fiber, being capable Tbps transmission has been spreaded.

On behalf of the broadband communications over 100Gbps or the wave shap measurement, SFQ circuits using the oxide high temperature superconductor has been developed as a high speed sampling oscilloscope, achieved 450GHz for the circuit alone. Furthermore, as a part of a 150fs ultra high speed switching operation at the subbands in GaN-based quantum well, and a femto-second optical response of Al-Ga-As mesoscopic structures, the two dimensional photonic cryastal wave guide has been developed. Some fundamental functions such as streightness, bend and branch have been already verfied, expecting optical integrated circuits for operating the optical signals.

On the other hand, as the power optoelectronics to conver solar or light energy to electric energy, the solar cell is popularized. Now three kinds of solar cell are used practically. Singlecrystalline silicon solar cells with P-N junctions are usefull for an unattended substation, a lighthouse or an obsevatory. Amorphous or polycrystalline silicon solar cells with P-I-N junctions are usefull for a handy calculator, an electronic game or a solar radio, because of its small size and responsibility for weak light environments. Compound semiconductor solar cells such as Ga-As system with P-N junctions are applied to an artificial satellite, because of its high conversion efficiency over 35% and reliability for long time operation.

Furthermore, the surface emitting laser has an epochmaking

development. Especially, realization of the blue light emitting laser has suggested to come solid full-color displays arrayed with three essential LEDs of red light, green light and blue light one. Because GaP-LED for red light, GaAlAs-LED for green light and GaN-LED for blue light are available. In the potable phone, the digital camera, the digital watch and so on, the solid full-color displays are usefull for small-sizing and light-weighting them.

In summary, we believe the sustainable development in this century on the basis of IT industries and PT industries, and expect more challengeable researches and developments of metals, ceranics and their application devices, as the basic materials for strengthening industrial competitiveness.

On an analisis of Nippon Kogyo Shimbun in Spring, 2003, the market size related to advanced materials and nano-technologies will be increased upto 26,000 billion yen in 2010. This market is consisted by electronics, power electronics, optoelectronics, process materials, fuel cell etc.

Thus, we should do our best in developing advanced materials and nano-technologies to the electronic electrtic materials on the basis of globalization. As the result, we should work toward our goal of the sustainable development in Japan through strengthening industrial competitiveness and commercialization of advanced products.

(Manuscript received Sept. 24, 2003)

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