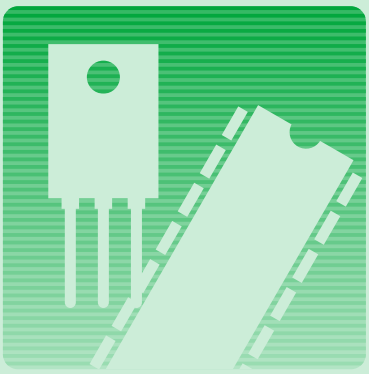
# Electronic Devices



Semiconductors
Disk Media

## Outlook

**Semiconductors**

Power semiconductors are being used in an increasingly wide range of applications in the fields of automobiles, photovoltaic power generation and wind power generation in addition to industrial equipment and home appliances. This is occurring along with the increase in global energy demand and greater awareness of the need for energy saving and energy creation in order to conserve the global environment, represented by a reduction in $CO_2$ emissions. Fuji Electric contributes to society by continuously developing power semiconductor products featuring high energy conversion efficiency, low noise and ease of use.

One representative example of power semiconductors is an insulated gate bipolar transistor (IGBT). The IGBT was developed in the 1980s, and underwent a change of generation of devices along with subsequent innovations such as loss reduction and high heat dissipation technologies. Fuji Electric's latest IGBT is now in the 7th generation. We have also worked on developing products that use silicon carbide (SiC) as a next-generation semiconductor material to replace silicon and developed an all-SiC module that applies the 1st-generation trench gate MOSFET.

For the industrial field and environment and energy field, we have developed a 1,700-V breakdown voltage high-power IGBT module that applies the latest 7th-generation IGBT technology. In addition to the product line-up with a package compatible with conventional products, we have developed a line of products with a new package, "High Power next Core (HPnC)," featuring high heat dissipation, low inductance and high reliability. HPnC is suited for modules to be used in the field of electric railways because of the features it offers, and we intend to deploy this product in the electric railway market in the future.

We have also promoted innovations in IGBT and free wheeling diode (FWD) technologies and developed an RC-IGBT. An RC-IGBT chip integrates an IGBT chip with a FWD chip, allowing for an improvement in the maximum rated current of the module package, and we are working to expand the line-up of products for the industrial field.

In the automotive field, Fuji Electric has developed the "F5114H" high-side 2-in-1 intelligent power switch (IPS). It applies the 4th-generation IPS technology and contribute to miniaturize electronic control units (ECUs) that are becoming intricate as electronic control are increasingly used. The SSOP-12 package, which has the same external dimensions as SOP-8 package, has been equipped with 2 chips that have the same functionality as that of previous products. This makes it possible to have 2 channels with the same footprint as one-channel products. For automotive DC-DC converters and chargers, we have developed the 2nd-generation SJ-MOSFET "Super J MOS S2A Series", which achieves high-efficiency power conversion. This product conforms to AEC-Q101, a reliability standard for automotive electronics. It has further reduced the on-state resistance standardized by the unit area and improved the trade-off between switching loss and voltage surge during turn-off switching, thereby achieving both lower loss and better ease of use. In the field of automotive IGBTs used for motor drives of hybrid electric vehicles and electric vehicles, we are developing a line-up of products using the above-mentioned RC-IGBTs and our original direct liquid cooling structure.

Regarding discrete products, we have commercialized the "High-Speed W Series" high-speed discrete IGBTs with TO-247-4L package, which achieves high-efficiency power conversion, for UPSs and photovoltaic power generation PCSs. Having 4 terminals in this package can lower the emitter common inductance of the gate drive circuit and the wiring inductance of the gate-emitter loop, significantly reducing the switching loss. In addition, we have worked to meet market demands for improved efficiency of the power circuit during light loads, reduced standby power and system cost reduction. To this end, we have offered the "FA1A60N" critical mode PFC control IC capable of power factor improvement and the "FA6B20N" LLC current resonant control IC, which operates soft switching control, for high-efficiency power supplies. These can be interconnected to have automatic switching between operation

modes, and this has led to a significant improvement in efficiency during light loads and a reduction in standby power while accommodating a wide range of input voltages of 85 to 264 V AC. It has also successfully reduced the number of components. Fuji Electric intends to continue developing environmentally friendly power semiconductor products and contribute to the creation of responsible and sustainable societies.

### Disk Media

Along with the advent of the IoT age, the global volume of information is expected to dramatically increase and hard disk drives (HDDs) are expected to continue to undertake an important role of offering high-capacity and low-cost storage. As a magnetic recording media supplier for HDDs, Fuji Electric started the mass production of 2.5-inch media with a recording capacity of 1 TB/disk, which is the industry's largest, and 3.5-inch media with a recording capacity of 1.33 TB/disk for nearline servers in FY2016. We intend to continue developing and offering media meeting market demands and contribute to the development of an IT-based society.

## Semiconductors



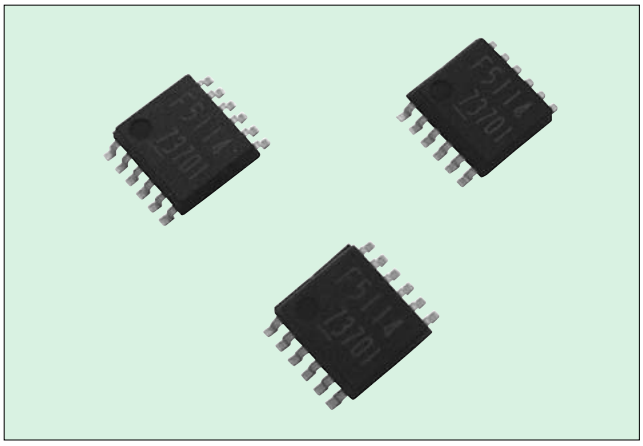
### 1 "F5114H" High-Side 2-in-1 IPS for Automobiles

There are demands for miniaturization and higher reliability of semiconductors in the field of automotive electrical equipment. In response to them, Fuji Electric has developed the "F5114H" high-side 2-in-1 intelligent power switch (IPS) for automobiles using the process and device technology of the 4th-generation IPSs for the purpose of further miniaturization.

The SSOP-12 package has the same external dimensions as those of the SOP-8 package. Further, it is equipped with 2 chips that have equivalent functionality to that of conventional products, including over-current protection, over-temperature protection, open load detection and low-voltage detection. Each chip is separated with lead frames and operates independently, allowing a channel to avoid affecting operation of the other channel even when it fails. The product is designed to ensure reliability against higher temperatures of the device and environment by employing reliable wire that can be used in a high-temperature environment.

Reference: FUJI ELECTRIC REVIEW 2016, vol.62, no.4, p.261

Fig.1 "F5114H"

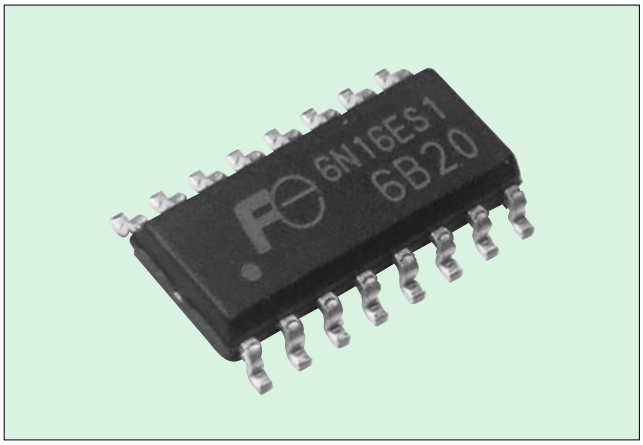


### 2 "FA6B20N" LLC Current Resonant Control IC for High-Efficiency Power Supplies

Power supplies with an output power of over 100 W widely use LLC current resonant circuits capable of soft switching control, which is effective for noise reduction, and are required to improve efficiency and reduce system cost. Fuji Electric has developed the "FA6B20N" LLC current resonant control IC, which achieves further efficiency improvement during light loads and the reduction of the number of components while accommodating a wide range of input voltages of 85 to 264 V AC. The main features of power supplies that use this IC are as follows:

(1) By interconnection with the "FA1A60N" power factor correction (PFC) control IC, a power supply can improves its entire efficiency, including that of PFC circuit, during light loads (efficiency with output power of 5 W: 75%).
(2) Power consumption in the standby state can be reduced.
(3) Heavy load start-up is possible during low input voltage.
(4) Automatic switching between normal state and standby state is provided.

Fig.2 "FA6B20N"



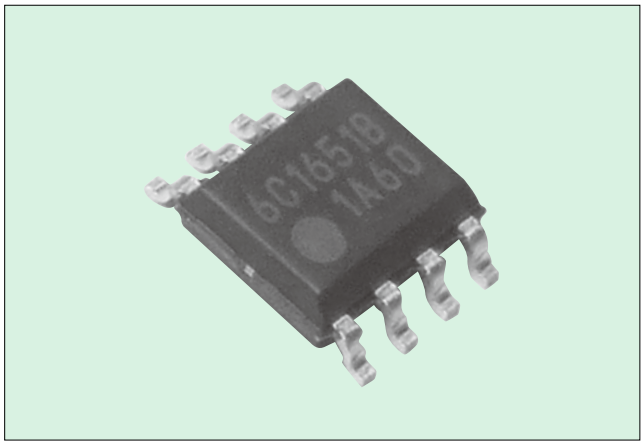
## Semiconductors

### 3 "FA1A60N" Critical Mode PFC Control IC for High-Efficiency Power Supplies

Switching power supplies with a relatively large capacity used for electronic devices are required to have a power factor correction (PFC) circuit for suppressing a harmonic current. Fuji Electric has developed the "FA1A60N" critical mode PFC control IC. It achieves both improved efficiency and lower standby power during light loads of power supplies. In addition to the existing bottom skip function (maximum frequency limiting), which improves efficiency during light loads, a burst function, which intentionally provides a switching stop period in the standby state, further reduces standby power consumption while maintaining a PFC output voltage. Furthermore, burst operation can be provided according to the input voltage information by interconnecting with the "FA6B20N" LLC current resonant control IC. This makes the standby power consumption less dependent on the AC input voltage, allowing for a further improvement in the power supply characteristics. The main features are as follows:

○ PFC efficiency 90.4% (with 5 W load at 100 V AC: 77.4% with conventional product)

Fig.3 "FA1A60N"

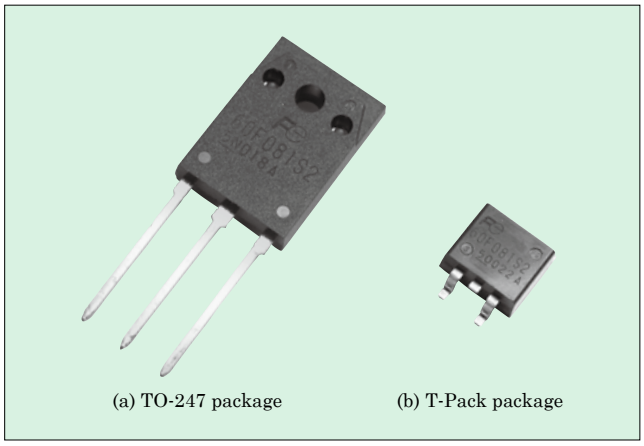


### 4 "Super J MOS S2A Series" 2nd-Generation SJ-MOSFET for Automotive Applications

Fuji Electric has developed the "Super J MOS S2A Series" 2nd-generation SJ-MOSFET for automotive applications that is a power MOSFET suited for automotive DC-DC converters and chargers. This product has achieved a 25% reduction in the on-state resistance per unit area from conventional products. It also offers a 5% reduction in the surge voltage during turn-off (when used for the chopper circuit, driving with 2-Ω gate resistance). In this way, the product features a lower loss than that of conventional products, making it easier to use. It conforms to AEC-Q101, a reliability standard for automotive electronics, and meets diverse demands with the following product line-up:

(1) Breakdown voltage: 400 V, 500 V and 600 V
(2) On-state resistance: 25.4 to 160 mΩ (600-V breakdown voltage model)
(3) Package: TO-247, T-Pack

Fig.4 "Super J MOS S2A Series"



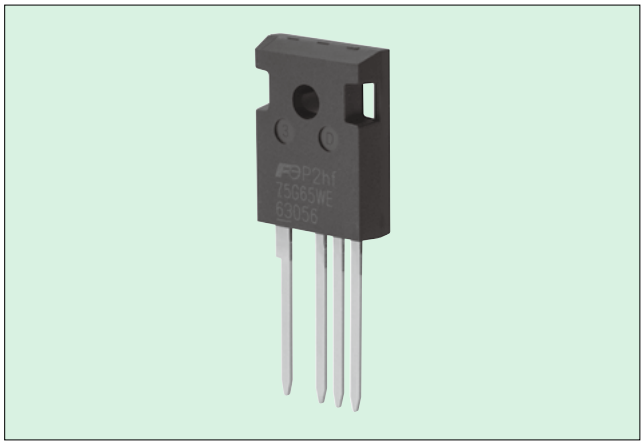
(a) TO-247 package (b) T-Pack package

### 5 "High-Speed W Series" High-Speed Discrete IGBT in TO-247-4L Package

Uninterruptible power systems (UPSs) and power conditioning systems (PCSs) are increasingly being required to improve efficiency. For that equipment, Fuji Electric has developed the "High-Speed W Series" high-speed discrete insulated gate bipolar transistor (IGBT) contained in the TO-247-4L package, which has an additional sub-emitter terminal. As compared with the conventional product in the TO-247 package, a significant reduction in switching loss has been achieved. The main features are as follows:

(1) Reduced common inductance of the emitter
(2) Reduced switching loss by lowering the wiring inductance of a gate-emitter loop
(3) Turn-off loss: Reduced by approximately 15% (from TO-247)
(4) Turn-on loss: Reduced by approximately 55% (from TO-247)
(5) Rated voltage/current: 650 V/50 A, 75 A, 1,200 V/40 A

Fig.5 "High-Speed W Series" (TO-247-4L package)



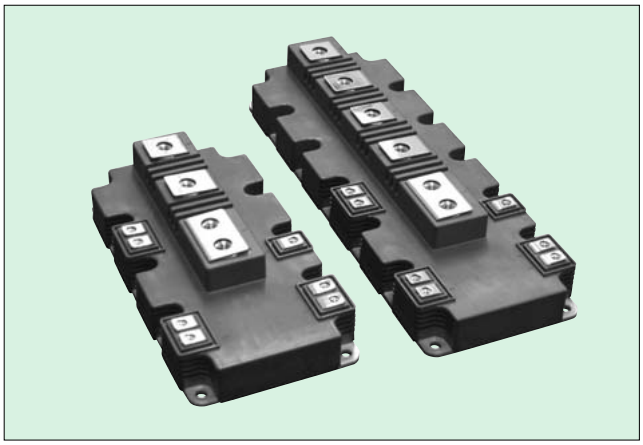
## Semiconductors

### 6 7th-Generation "X Series" 1,700-V High-Power IGBT Module

Demand is increasing for high-power IGBT modules for high-voltage, high-capacity inverter systems and power conversion equipment of wind power generation systems used in the field of industrial infrastructure. Fuji Electric has developed high-power IGBT modules with a rated voltage of 1,700 V of the 7th-generation "X Series" IGBT module.

Fuji electric has successfully reduced power dissipation by improving the characteristics of semiconductor chips and significantly reduced the thermal resistance by using newly developed high thermal conductivity insulating substrate. These new technologies realized a maximum rating of 1,700 V/1,800 A that could not achieved by conventional technology. In addition, the continuous operation guaranty temperature has been increased to 175°C from the conventional 150°C by improving $\Delta T_j$ power cycle capability and higher heat withstand capability of the insulating silicone gel. The new product can satisfy market demands such as miniaturization, lower power dissipation, higher reliability and so on.

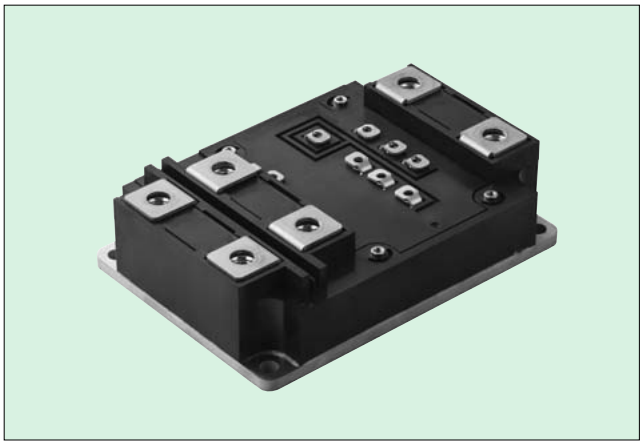
Fig.6 7th-generation "X Series" 1,700-V high-power IGBT modules



### 7 "HPnC" Package for High-Power IGBT Modules

Power conversion equipment are being demanded to further increase current density and improve efficiency. To meet them, Fuji Electric has developed the "HPnC" (High Power next Core), a new package for high current and voltage for the electric railways and renewable energy (photovoltaic power generation and wind power generation) sectors. The features of HPnC include lower loss and $T_{jop}$ of 175°C achieved by applying the 7th-generation chip technology. In addition, heat dissipation has been improved by applying an AlN isolation substrate as a packaging technology. Furthermore, the main terminal structure applying a laminated structure has made it possible to reduce the internal inductance to 10 nH, realizing high-speed switching. RoHS compliance has also been achieved by ultrasonic terminal bonding. By applying these technologies, a 12% current density increase and efficiency improvement have been realized as compared with the conventional "HPM."

Fig.7 "HPnC"



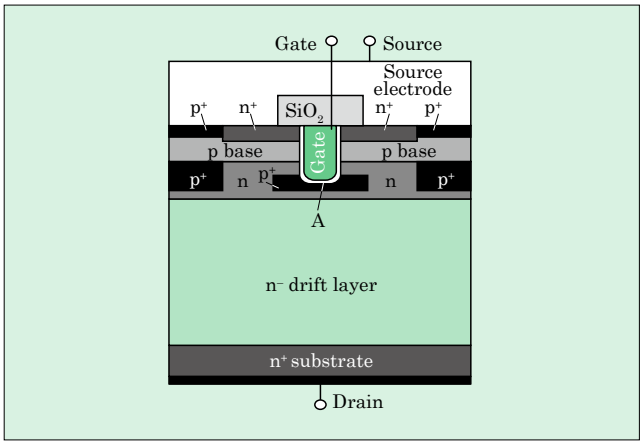
### 8 6-Inch SiC Trench Gate MOSFETs

Fuji Electric has used a 6-inch silicon carbide (SiC) substrate to develop SiC-MOSFETs with a trench gate structure featuring a further reduced on-state resistance during operation. A trench gate SiC-MOSFET with a 1,200-V rating uses smaller design rules with the cell pitch size approximately halved from that of the conventional products having planar gate structure, reducing the on-state resistance per unit area by about 50%. The trench gate SiC-MOSFETs developed have a structure with the gate oxide film at the bottom of the trench covered with a p-type diffusion layer (see A in the figure). This structure mitigates the electric field in the gate oxide film when a reverse voltage is applied, improving the reliability of the gate oxide film.

In FY2017, we plan to develop trench gate SiC-MOSFETs offering even higher breakdown voltage with the 1,700-V and 3,300-V ratings.

Reference: FUJI ELECTRIC REVIEW 2016, vol.62, no.4, p.218

Fig.8 Cross-sectional structure of SiC trench gate MOSFET



## Semiconductors

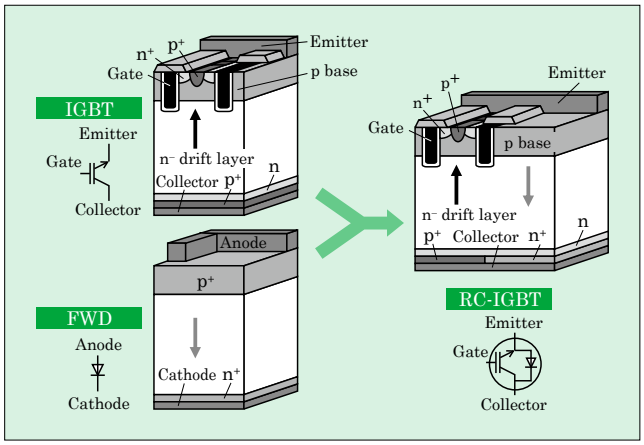
### 9 RC-IGBT Chips for Industrial Applications

To increase the rated current of insulated gate bipolar transistor (IGBT) modules, Fuji Electric is developing an RC-IGBT chip integrating an IGBT chip with a free wheeling diode (FWD) chip. By using this chip, products with a rated current that cannot be achieved with the 7th-generation IGBT modules can be developed and mounted in a package that is smaller than conventional products.

To reduce the die size of a 1,200-V breakdown voltage device by 25% from the existing 7th-generation IGBT and FWD chips, Fuji Electric has conducted measures as follows: establishing photolithography technology for the wafer backside, optimally designing the pattern and pitch of the IGBT and FWD portions, and establishing an optimum lifetime control method for RC-IGBT chips. This has made it possible to improve the maximum rated current with the same package by 20%.

Reference: FUJI ELECTRIC REVIEW 2016, vol.62, no.4, p.241

Fig.9 Cross-sectional diagram of RC-IGBT chip

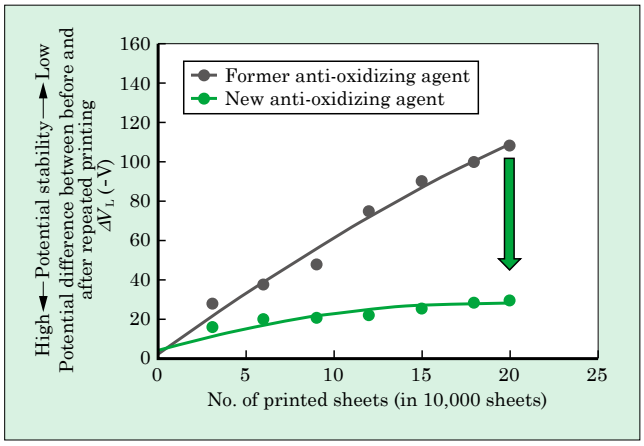



### 10 Negatively Charged High-Functionality Organic Photoconductors

The lifetime of electrophotographic printers and copiers are becoming longer in terms of maintenance free operation while increasing the operating speed. Photoconductors, which are the main component, are required to offer high-speed response and high durability. Charge transport materials with high-speed response have the drawback of being susceptible to unstable potential behavior due to the influence of discharge products.

Fuji Electric is developing a negatively charged high-functionality organic photoconductor with stable potential behavior that can endure long-term use. The surface of a photoconductor is oxidized by the influence of discharge substances generated from the charged components. Hence, in view of the structure of the charge transport material to be applied to the surface layer, as well as compatibility, we have selected the structure of the anti-oxidizing agent and optimized the amount of agent added. These have led to a significant improvement in the potential behavior.

Fig.10 Improvement of potential stability by anti-oxidizing agent




## Disk Media

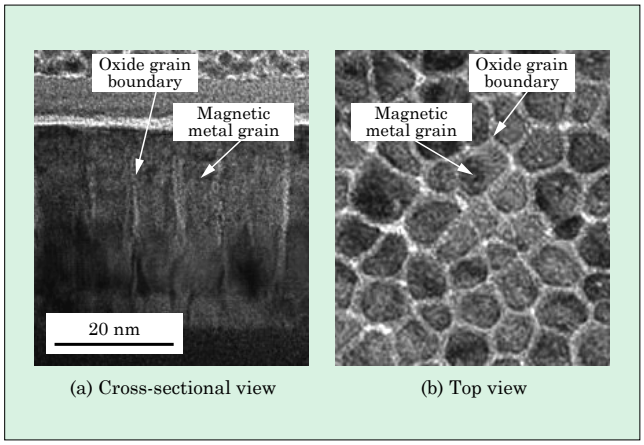
### 1 Recording Density Improvement of Shingled Magnetic Recording (SMR)-Based Magnetic Recording Media

In the hard disk drive (HDD) market, there is ever-increasing demand for recording density as the driver of the market is shifting from PC to data center applications. Accordingly, commercialization of HDDs that employ shingled magnetic recording (SMR), which is a new recording system, is in progress.

To develop recording media best suited for SMR, Fuji Electric is working on the design optimization of a multilayer thin film including a multilayer granular magnetic layer. With reduction and uniform of intergranular coupling strength and with proper control of inter-layer coupling strength, we have realized a high level of both linear density and track density to achieve a high areal density of 1,330 Gbits/in$^2$.

This technology has been applied to the media for mobile HDD (1 TB/disk) that started mass production in September 2016 and is planned to be gradually applied to media for data center HDD in the future.

Fig.11 TEM images of magnetic recording media



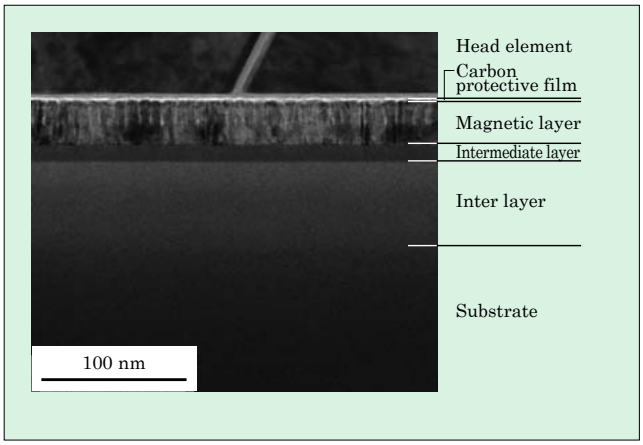

(a) Cross-sectional view (b) Top view

## Disk Media

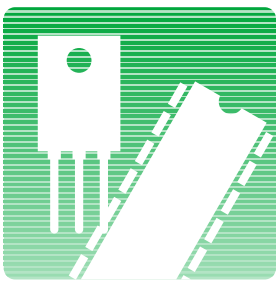
### 2 High-Reliability Magnetic Recording Media for Nearline Servers

For nearline servers, which require particularly high capacity and reliability among HDD applications, Fuji Electric has developed a 3.5-inch aluminum magnetic recording medium with a recording capacity of 1.33 TB/disk. It is required to provide high reliability appropriate for the operating environment, as well as a shorter distance between the head and the magnetic layer to increase the recording density. Accordingly, we optimized the sputter deposition and cleaning conditions to reduce the number of small defects of a few nanometers in height. In addition, we improved corrosion resistance by reducing the film thickness distribution of the carbon protective film by 10% from that of the conventional product and restraining the increase in surface roughness during sputter deposition. Furthermore, we doubled the sputtered film hardness from that of the conventional product, thereby achieving mechanical durability. By taking these approaches, we acquired qualification of the customer and started mass producing the product in March 2017.

Fig.12 Image of head disk interface (HDI)





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