

**RESEARCH EXPRESS**

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## Emerging Functional Single Crystal Market

~ SiC, GaN, etc. ~

### ➤ Research Outline

Yano Research Institute has conducted a study on market trends and technology trends of the functional single crystals expected to grow in future, represented by SiC (silicon carbide) and GaN (gallium nitride). The functional single crystals researched could be broadly classified as semiconductor crystals such as SiC and as wavelength conversion crystals for laser light (nonlinear optical crystals). Undoubtedly, these crystals will be playing important roles in application to the electronic devices and optical devices.

1. Research items:

[Wide-gap semiconductor] SiC, GaN, AlN, ZnO, single-crystal diamonds, [Nonlinear optical crystal] ferroelectric crystals, wavelength conversion crystals, DAST, [Others] fluoride, scintillator, protein crystals

2. Research targets: Major Japanese companies handling the research items listed above

3. Research period: From June 2007 to September 2007

4. Research methodologies: Primary methodology of face-to-face interviews with relevant personnel of research target companies engaging in manufacturing and development of the above research items was employed, supplemented and reinforced by telephone interviews and email follow ups.

### ➤ Summary of Research Findings

• **Market size of SiC single crystals is 4 billion Yen in 2006 and expected to reach 5 billion Yen in 2007**

Currently, SiC single crystals are supplied only by Cree, Inc., a U.S. company. However, some Japanese companies including Nippon Steel have already started developing SiC. The SiC currently shipped is mostly used for R&D purpose, but the shipment volume has been growing in accordance with progress of R&D that is closer to the phase of commercialization.

• **Market size of GaN single crystals is 6 billion Yen in 2006 and expected to reach 12 billion Yen in 2007**

Basically, only one company, Sumitomo Electric Industries, is supplying GaN single crystals at this moment, but the demand is sharply increasing particularly for the blue-violet laser.

• **Forecast shows the market size of SiC single crystals will be 10.5 billion Yen in 2010 and 30 billion Yen in 2015, and of GaN 29.7 billion Yen in 2010 and 57.5 billion Yen in 2015. Furthermore, markets of AlN (forecasted market size in 2015: 5 billion Yen) and ZnO (forecasted market size in 2015: 10 billion Yen) are expected to emerge.**

Both Japanese domestic and overseas electronic device manufacturers have activated their R&D for SiC electronic devices, triggered by the advent of high grade SiC single crystals. Especially, SiC is expected to start replacing Si for the use of high-voltage discrete components. The manufacturers have already started using GaN for some electronic devices other than LD and LED, and the number of such manufacturers seems to be gradually growing. Concerning AlN (Aluminum nitride) and ZnO (Zinc oxide), we have confirmed some manufacturers have already released products that AlN or ZnO is used for, and practical use of these materials is certainly becoming closer.

➤ **Report format:**

Published report: “Emerging Functional Single Crystal Market ~ SiC, GaN, etc. ~”

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## Description of Research

➤ **Research Background and introduction of the functional single crystals as research items**

The most popular crystal used for the semiconductor devices of the electronics field is silicon (Si). A huge market has already established for silicon and the substrates of over 400mm are already being manufactured. On the other hand, there are some other single crystals prospective for market growth with expansion of application to wider variety of devices as a result of recent R&D activities. Such crystals include AlN (aluminum nitride), ZnO (zinc oxide) and other optical crystals.

Although these single crystals are expected to be used widely for substrates of electronic devices and optical devices, many of them are still staying on the stage just before the commercialization or mass production since technologies of substrate crystal growth, thin film growth and device formation have not fully established.

With the background as described above, our focus in this study is on the single crystals that have future potential of market growth in spite of current immature markets.

The functional single crystals as the target items could be classified as semiconductor crystals such as SiC and GaN and as wavelength conversion crystals (nonlinear optical crystals) of laser light. In the study report, we have also referred to some other single crystals including CaF<sub>2</sub> that have recently shown remarkable technological development.

**Table. List of Functional Single Crystals Selected as Research Targets**

Classification	Crystal Materials	Method	Application	Organizations Engaged in Material Development (Bulk crystals, Wafer)
Wide band gap semiconductor	SiC (Silicon Carbide)	Sublimation method, HTCVD, Solution growth method	Light-emitting devices, Power semiconductor devices	Cree, Nippon Steel, Showa Denko, Sixon, Bridgestone, TOYOTA Central R&D Lab, HOYA, Sumitomo Metal Industry, AIST, etc.
	GaN (Gallium Nitride)	HVPE method, Solution growth method (Na flux method, Hydrothermal method, etc.)	Light-emitting device, HEMT, SIT	Sumitomo Electric Industries, Hitachi Cable, Mitsubishi Chemical, Furukawa, etc.
	AlN (Aluminum Nitride)	HVPE method, Sublimation method, Solution growth method, Flux method,	Ultraviolet light-emitting devices, GaN substrates, High-power and high-frequency devices	Sumitomo Electric Industries, Sumitomo Metal Industry, Toyoda Gosei, NGK Insulators, Fujikura, etc.
	ZnO (Zinc Oxide)	Skull melting method, CVT method, Hydrothermal synthesis method	Light-emitting devices, GaN substrates, Replacement of ITO	Tohoku University, Tokyo Denpa, etc.
	Single crystal Diamond	Plasma CVD method, etc.	Electronic devices, etc.	AIST, etc.
Nonlinear optical crystals	Ferroelectric Crystal (LiNbO <sub>3</sub> , LiTaO <sub>3</sub> )	Crucible pulling method	Optics applications, Wavelength conversion, QPM materials (PPLN)	Oxide, Matsushita Electric Industrial, etc.
	Wavelength Conversion Crystals (LBO, CLBO, etc.)	Crucible(Agitation growth)	Optical materials, Wavelength conversion	Oxide, Osaka University
	DAST	Gradient method, Gel growth method	Terahertz magnetic wave generation, Electric field sensors, etc.	Osaka University, Furukawa, etc.
Others	Fluoride (CaF <sub>2</sub> , etc.)	Bridgman method, CZ method(Crucible)	Optic materials (UV lenses, etc.), etc.	Nihon Kessho Koogaku, Applied Engineering, Tokuyama, Schott, etc.
	Scintillator	Crucible pulling method	Radiation detection devices, PET	Hitachi Chemical, Dai-ichi Kiden, etc.
	Protein Crystal	Vapor diffusion method, Two solution method	Analysis of protein structure	Osaka University (SOSHO)

➔ **Current market scale of the functional single crystals**

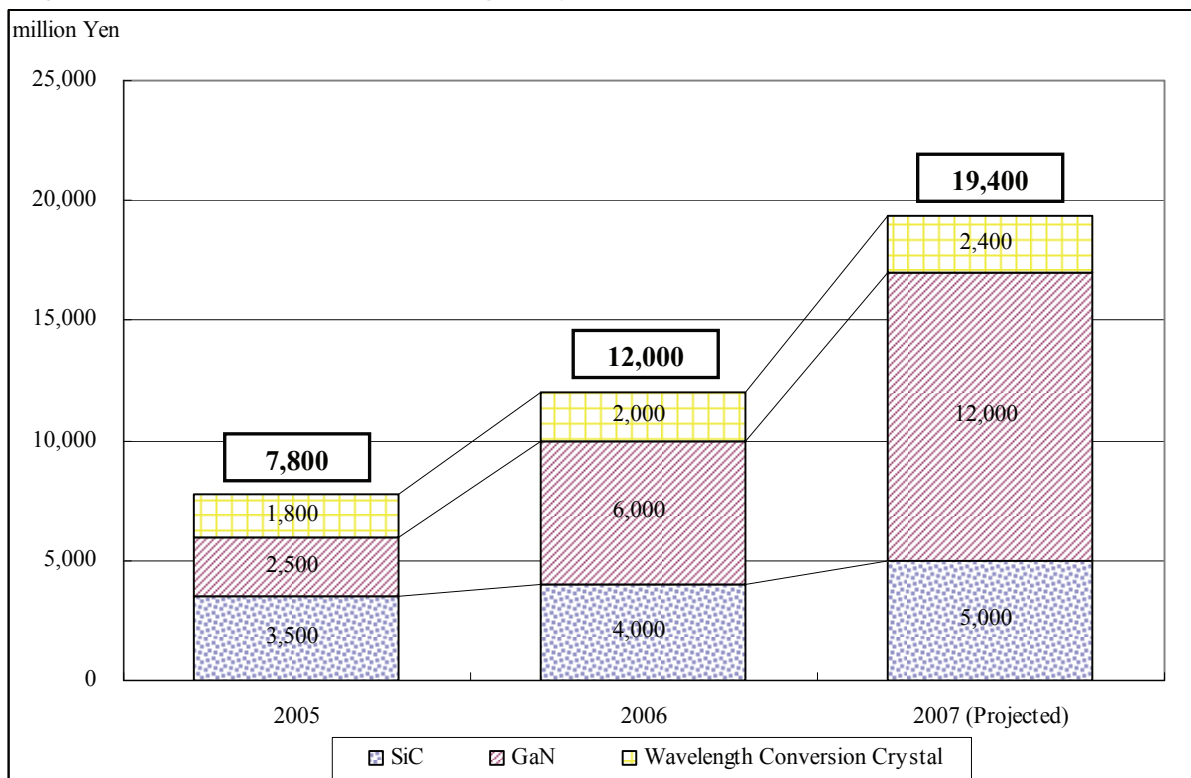
All single crystals picked up in this study project still remain in the amount of between a few billion Yen to 10 billion yen in terms of market scale since the markets of these crystals are just emerging. Furthermore, the markets of AlN, ZnO, single-crystal diamonds, etc. have not even identified so far.

As for SiC, the number of commercialized devices is limited at this moment, and most use is for research and development. With the progress of R&D closer to commercialization, however, demand has been constantly increasing. While the current major supplier of SiC is only Cree, Inc., a U.S. company, some Japanese companies including Nippon Steel have succeeded in commercializing SiC and started supplying even though the shipment volume is small.

Major application of GaN is the substrates of blue-violet semiconductor laser (LD) to be used for the optical pickups of the next generation DVD, and the demand has been sharply growing since 2006 for this application. As of now, only Sumitomo Electric Industries is supplying most part of the demand.

Certain scale of market is already established for the wavelength conversion crystals though the market scale is small at this moment. The market is expected to expand in future, however, in accordance with demand growth of the optical wavelength light laser and ultra-violet light laser used for the laser display devices, and with commercialization of new single crystals.

**Figure. Market Scale of Functional Single-Crystals**



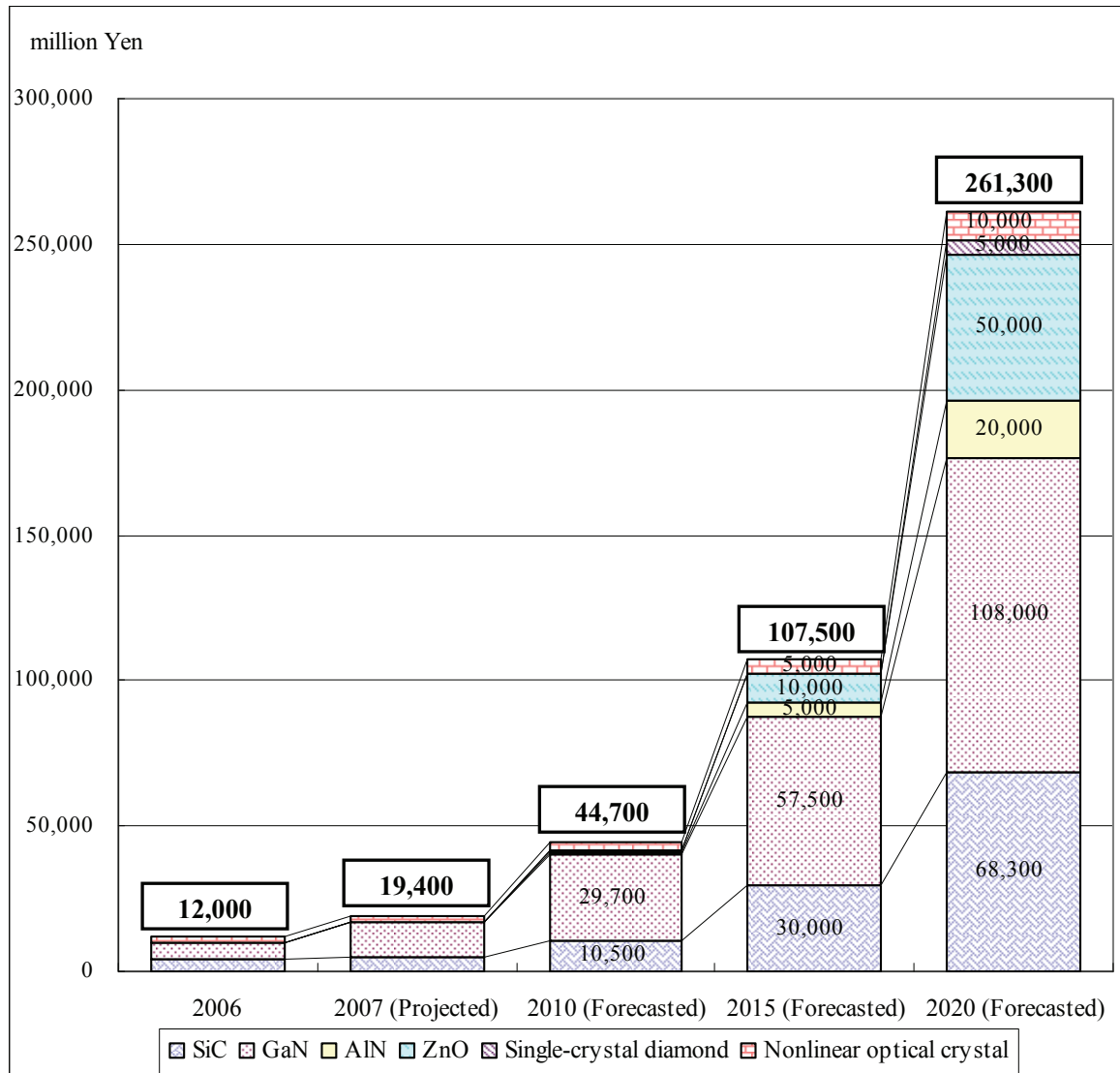
(Estimated by Yano Research Institute Ltd.)

**Table. Market Scale Forecast of Functional Single-Crystals (Worldwide Market)** (million Yen)

	2006	2007 (Projection)	2010 (Forecast)	2015 (Forecast)	2020 (Forecast)
SiC	4,000	5,000	10,500	30,000	68,300
GaN	6,000	12,000	29,700	57,500	108,000
AlN	-	-	1,000	5,000	20,000
ZnO	-	-	500	10,000	50,000
Single-crystal diamond	-	-	-	-	5,000
Nonlinear optical crystal	2,000	2,400	3,000	5,000	10,000
<b>Total</b>	<b>12,000</b>	<b>19,400</b>	<b>44,700</b>	<b>107,500</b>	<b>261,300</b>

(Estimated by Yano Research Institute Ltd.)

**Figure. Market Scale Forecast of Functional Single-Crystals (Worldwide Market)**



(Estimated by Yano Research Institute Ltd.)