Company Profile
1. Company Profile

FLOSFIA is a startup spun out from KYOTO University, to commercialize the MIST CVD technology

FLOSFIA's Corporate Profile

Founded in March 31, 2011
Head Quartered in Kyoto University, Katsura Capmus
Business areas include Power Oxide semiconductor devices and Mist EPITAXY solution
Founded by Toshimi HITORA (CEO), Kentaro KANEKO, Ph.D. (CSO) Shizuo FUJITA
Co-developed with Kyoto University, Advanced Electronic Materials (Fujita Lab), Ritsumeikan Univ., Electrical & Electronics Eng (Araki Lab)
Share holders include T Hitora, K Kaneko, S Fujita, UTEC, Nissay capital, Brother etc
2. Power Device Market Issue

Enormous power conversion loss from generation to consumption: a major social concern
Low-loss and low-cost power devices being essential for the solution

The power device industry trying hard to achieve such a low-loss and low-cost power device
("Pain" in the current industry)

- Power conversion loss being a major social concern

- Proposals of SiC and GaN: limited in application due to Si ratio (5x to 10x) and high cost

3. Our Goal

Market pain: More than 10% of all electricity is ultimately lost due to conversion inefficiencies of silicon power devices.

- Great expectations for a low-loss and low-cost power device
- Difficult to achieve such device by extension of existing technology (SiC and GaN).

FLOSFIA’s solution: Gallium oxide power devices

Global power device market

- Initial target: $26b
- Ultimate target: $26b
- Next gen power devices: $2.8b
- 63.6% CAGR

Source: "Power semiconductor global market research 2014" by Yano Research Institute Ltd.
4. Property Comparison with Competing Materials

**Ga$_2$O$_3$: excellent material compared with Si, SiC, GaN**

Ga$_2$O$_3$ including various crystal structures; α-Ga$_2$O$_3$ having advantageous physical properties

<table>
<thead>
<tr>
<th>Name of material</th>
<th>Si</th>
<th>4H-SiC</th>
<th>GaN</th>
<th>β-Ga$_2$O$_3$ (Corundum structure)</th>
<th>α-Ga$_2$O$_3$ (Corundum structure)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bandgap $E_g$ (eV)</strong></td>
<td>1.1</td>
<td>3.3</td>
<td>3.4</td>
<td>4.5</td>
<td>5.3</td>
</tr>
<tr>
<td><strong>Mobility $\mu$ (cm$^2$/Vs)</strong></td>
<td>1,400</td>
<td>8,000</td>
<td>1,200</td>
<td>200</td>
<td>300 (estimate)</td>
</tr>
<tr>
<td><strong>Dielectric breakdown field $E_c$ (MV/cm)</strong></td>
<td>0.3</td>
<td>2.5</td>
<td>3.3</td>
<td>6.5</td>
<td>10 (estimate)</td>
</tr>
<tr>
<td><strong>Relative dielectric constant</strong></td>
<td>11.8</td>
<td>9.7</td>
<td>9.0</td>
<td>10</td>
<td>10 (estimate)</td>
</tr>
<tr>
<td><strong>Baliga’s figure of merit $\alpha$</strong></td>
<td>$\varepsilon \mu E_c^3$</td>
<td>1</td>
<td>340</td>
<td>870</td>
<td>1,231</td>
</tr>
<tr>
<td>$\varepsilon \mu E_c^2$</td>
<td>1</td>
<td>50</td>
<td>104</td>
<td>67</td>
<td>238 (estimate)</td>
</tr>
</tbody>
</table>
5. Benefits of Corundum Structured Gallium Oxide (α-Ga$_2$O$_3$)

FLOSFIA : committed to corundum structured (α-) gallium oxide
Use of families allowing earlier commercial production, ensuring high reliability and reduction in resistance!

Corundum families used for high quality devices at competitive prices

Using sapphire (Al$_2$O$_3$) substrate
- Mass produced as LED material
- Priced comparably to Si
- Great advantage of using commercially available substrates

Competing materials taking 20-30 yrs. for substrate development

Improving device quality
- Corundum families applied to electrodes, insulating films, p layers, the mixed crystal technique, etc. for construction of a plenty of device element processes

Fabrication of corundum families other than sapphire used to be difficult.
- A breakthrough made with "mist CVD" from Kyoto Univ.
  Achieving high quality crystals of various corundum families using sapphire!
Successively fabricating prototype diode (SBD) using $\alpha$-Ga$_2$O$_3$ to achieve world top-level data

**Ultra-low loss**
Reduction in on-state loss

Demonstrated world top-level data (October, 2015)
(Experiment with 30 µm φ microchip: approx. 0.01 A)

Power devices requiring 5+ A current
Succeeded in production of prototype diode (SBD) of $\alpha$-$\text{Ga}_2\text{O}_3$!}

Success in prototyping low on-resistance diode

Electrode 1 (Pt/Ti/Au)

$\alpha$-$\text{Ga}_2\text{O}_3$ (n−)

Electrode 2 (Ti/Au)

$\alpha$-$\text{Ga}_2\text{O}_3$ (n+)
Prototyping, including implementation, and evaluation in progress. Much faster switching speed than Si, expected to reduce the switching loss in the circuit implementation.

**Ultra-low loss**  
Reduction in switching loss  
Fast switching verified in an implemented device (TO220)

**Overcoming material problems**

- Original device structure achieving thermal resistance same as commercial SiC-SBD in packaged sample (TO220)
- Ga$_2$O$_3$ layer not being a bottleneck in thermal resistance

**Device structure**

- Using Ga$_2$O$_3$ thin film (10-μm)
- Using supporting material (metal) (Good heat dissipation, low on-resistance, ease of handling)

**Thermal resistance same as commercial devices confirmed in Ga$_2$O$_3$ implemented SBD!**

Successfully reduced thermal resistance

Assumption: thermal conductivity of 20 W/mK (estimated from β-Ga$_2$O$_3$ data), chip size of 0.8 mm sq., thickness of 10 μm

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Reference material</th>
</tr>
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<tbody>
<tr>
<td>SiC</td>
<td>12.5°C/W (TO220)</td>
</tr>
</tbody>
</table>

- Original device achieving thermal resistance same as commercial SiC-SBD in packaged sample (TO220)
- Ga$_2$O$_3$ layer not being a bottleneck in thermal resistance

<table>
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<tr>
<th>Device structure</th>
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<tbody>
<tr>
<td>Lead frame</td>
</tr>
<tr>
<td>Ga$_2$O$_3$ semiconductor layer</td>
</tr>
<tr>
<td>Supporting material (metal)</td>
</tr>
<tr>
<td>Resin</td>
</tr>
</tbody>
</table>

0.8mm sq.

13.9°C/W (TO220)

0.8°C/W (Ga$_2$O$_3$ layer)

New technology α-Ga$_2$O$_3$

Discovery of p-type corundum structured material “α-Ir₂O₃” for device integration in combination with α-Ga₂O₃. Breakthrough to the world’s first normally off FET (2nd device)!

Overcoming material problems

Discovery of p-type corundum structured material "α-Ir₂O₃"

- Lattice mismatch between Ga₂O₃ and Ir₂O₃ as small as 0.3%
- Confirmed high Hall mobility of 2.3 cm²/Vs (carrier concentration of 1.0 × 10²¹/cm³) by measuring the Hall effect
- Mist CVD available for film deposition

α-Ir₂O₃ and other corundum family materials

![Graph showing band gap and lattice constant along α-axis for various corundum materials](image)

XRD profiles

Diffraction spots
Successfully developed mass production basic technology using Ga$_2$O$_3$ thin film and supporting material (metal)!

Production process development

Successfully launched wafer process by developing a new production method applicable to mass production

- Apply Ga$_2$O$_3$ thin film (10-μm)
- Ga$_2$O$_3$ semiconductor layer
- Sapphire substrate

Supporting substrate (metal)
- Cu-based metal, etc. for the supporting substrate
- (Expecting good heat dissipation, low on-resistance, ease of handling)

Ga$_2$O$_3$ semiconductor layer
- Succeed in crystal growth to the mass production size of 4 in.
- Inimitable

Supporting substrate (metal)

Ga$_2$O$_3$ semiconductor layer
- Earlier commercial production

Supporting substrate (metal) and electrode

1) Minimizing R&D
Using mass produced sapphire substrates, no need for the long-term (10-20 yrs.) substrate development!

2) Achieving vertical devices*
Removing the sapphire substrate as an insulator

* Vertical device
A structure with electrodes on both sides of the chip to enable higher current

1) Inimitable
The original technology, mist CVD, enables high quality Ga$_2$O$_3$ semiconductor

2) Enlarged diameter
Succeeded in crystal growth to the mass production size of 4 in.

1) Good heat dissipation
Minimizing thermal resistance (less than SiC) by thinning the film

Turning low thermal conductivity into an advantage!

2) Low Substrate Resistance
Reducing the resistance to 1/50 - 1/100 of SiC substrate (commercial product)

Minimizing substrate resistance, as a bottleneck in the resistance of vertical devices

3) Incomparably low cost
1/3 (for the same chip area) - 1/10 (for miniaturized chip) of SiC

Taking advantage

Meeting the market needs

CS International Conference 2017
Aim to win a position in the commercial market. To be the most preferred material by taking advantage of low loss and low cost! Further aiming at the "high voltage market" by making use of the superior material properties, at the "low voltage market" by making use of cost competitiveness!

FLOSFIA's target markets

α-Ga$_2$O$_3$
Final product: semiconductor device including diode (SBD). Wafers to be produced in-house to establish key technology. The other processes in cooperation with external fabricators.

Value chain

FLOSFIA business areas

Material manufacturers

Raw materials → Substrate → Wafer (self-supported film) → Pre-device process → Post-device process → Discrete module → Final product

Semiconductor manufacturers (pre-process, post-process)

Subcontract ↓ ↓ ↓ ↓ Delivery

Sales to device users (direct sales, agent sales)

FLOSFIA

Self manufacture

Outsourcing (general purpose products) → In-house production → Production subcontract → Collaboration with existing semiconductor manufacturers
9. Mist CVD

Employing mist CVD, enabling good-quality corundum family production

**Conventional CVD**

- Semiconductors made from gas (common practice)
- Raw materials supplied to a deposition chamber as a gas
  - Raw materials limited to those with a boiling point lower than the deposition temperature
  - Raw materials being hazardous
- Semiconductors made in vacuum (common practice)
- Vacuum pump needed
  - Limitation in area increase, high in costs, difficulty in miniaturization

**Mist CVD (MIST EPITAXY®)**

- Made from liquid, particularly "water" (innovative!)
- Raw materials supplied to a deposition chamber as a mist
  - Successfully producing corundum families of good crystal quality for the first time. Widely developed in dopants and mixed crystals.
- Made in non-vacuum (innovative!)
- No vacuum pump required
  - Achieving area increase, cost reduction, miniaturization, and high throughput
### Metal oxide film Application examples

<table>
<thead>
<tr>
<th>Metal oxide film</th>
<th>Application examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gallium oxide</td>
<td>Power device</td>
</tr>
<tr>
<td></td>
<td>LED substrate</td>
</tr>
<tr>
<td>Iron oxide</td>
<td>Semiconductor, magnetic material</td>
</tr>
<tr>
<td>Chromium oxide</td>
<td>Corrosion resistant film, protective film</td>
</tr>
<tr>
<td>Silicon oxide, aluminum</td>
<td>Insulating film</td>
</tr>
</tbody>
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<tr>
<td>Magnesium oxide</td>
<td>Insulating film</td>
</tr>
<tr>
<td>Copper oxide, nickel</td>
<td>P conductive layer of oxide PV</td>
</tr>
<tr>
<td>Titanium oxide</td>
<td>Photocatalyst</td>
</tr>
<tr>
<td>Indium oxide</td>
<td>Transparent conductive film for displays</td>
</tr>
<tr>
<td>Lithium oxide</td>
<td>Positive electrode, negative electrode, electrolyte of LIB</td>
</tr>
<tr>
<td>Zinc oxide, tin oxide</td>
<td>Electrically conductive transparent film for displays</td>
</tr>
</tbody>
</table>

### Mist CVD allowing fabrication of various metal oxide films ➞ to wide range of industries!

Metal oxide film fabricated on sapphire ➞

#### State of film
- Single crystal, polycrystalline, amorphous

#### Type of film

<table>
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Metal oxide examples fabricated by mist CVD: B, C, N, O, F, Ne, Al, Si, P, S, Cl, Ar, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Kr, Rb, Sr, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, I, Xe, Cs, Ba, Lanthanoid, Actinoid, Rf, Db, Sg, Bh, Hs, Mt, Ds, Rg, Cn, Uut, Uuq, Uup, Uuh, Uus, Uuo, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, Tl, Pb, Bi, Po, At, Rn, Other metals are available for film deposition. Feel free to make an inquiry.
11. Our Team [Representative Profile]

Leading the power device business since appointed representative of FLOSFIA with experience on product marketing in the previous career

Toshimi HITORA

Next generation semiconductor business frontier

[Academic Background]
March 2000: Completed molecular developmental biology course, Graduate School of Bioscience, Nara Institute of Science and Technology
March 1998: M.S. in Applied Biochemistry, Department of Industrial Chemistry, Graduate School of Engineering, Kyoto Univ.

June 2012 Representative director, President of ROCA Inc. (Currently, FLOSFIA Inc.)
Participating the business operations of ROCA Inc. (Currently, FLOSFIA Inc.) as one of the founders since its establishment in March 2011.
Joined the firm after resignation of the former representative due to the change in the business domain after challenging for the seawater desalination market.
Made a decision to target super energy saving power semiconductor device by applying our proven gallium oxide semiconductor deposition technology to the power semiconductor fields.

2005 - June 2012 Representative director, President of ALGAN Inc.
Founded the firm as the representative director and the president for application of aluminum gallium nitride semiconductor to UV sensors. After successfully developed a sensor device, applied products of the sensor also successfully developed. The applied products employed for, for example, production apparatuses by the world's leading company in the liquid crystal panel cleaning device field. Also offered commercial UV sensors to the market, resulting in adoption by NTT Docomo, a Japanese leading mobile telecommunication company, etc. Took part in the Intel Global Challenge (global business plan competition) on this topic, won the Asian district award (Intel-DST) and nominated as one of the finalist.
Left the position at the completion of the first prototype for smartphone cooperative system.
We wish to help innovation by green and clean technology and create products that contribute to society.

We would like to be an organization where diverse intelligence and wisdom (Sophia) flow to sophisticate the Sophia and flow it back to society for better daily life. We named the company "FLOSFIA" from such thoughts. Our goal - intelligence and wisdom coming in to benefit everyone by creating new values - is just like a flow of river. We keep striving for creating superior value to society through each project as collected intelligence and wisdom.