NO PROCESS CAN CHANGE ALONE: AN INTEGRATED APPROACH TO CMP CONSUMABLE DEVELOPMENT AND MANUFACTURING.
Welcome to Saint-Gobain

€42.5\textsubscript{BN} SALES IN 2019

1 IN 4 PRODUCTS SOLD TODAY DID NOT EXIST FIVE YEARS AGO.

More than 180,000 employees in 67 countries

Over 350 years of history

More than 3,700 researchers worldwide

One of the top 100 industrial groups in the world
Our industrial growth is driven by global research, development, and innovation

3,700 researchers
8 cross-business R&D centers
1 product out of 4 sold by Saint-Gobain today didn’t exist 5 years ago

Nearly 400 patents filed in 2017
About 100 development centers

* Source: Clarivate Analytics
The Surface Conditioning Promise

Some Surface Conditioning brands you may have seen:

- Cleaners, Coolants and Slurries
- Diamond Slurries and Compounds
- Micron and Nano Diamond Powders
- Mesh Diamond and CBN Powders
- Clear coat finishing compounds
Our outlook on electronic substrates materials: SiC continues to grow!

1. Individual processes have evolved, improved, and reached their limits with existing market solutions
2. Manufacturers need flexibility and capacity across sizes, quality grades, and targets
3. SiC is approaching commoditization due to consolidation and acquisitions in the market
4. Our technology development from 10+ years of working with SiC has enabled advanced solutions
No process can change alone: An integrated approach to CMP consumable development and manufacturing

**GROW**
- Fixed Diamond Wire
- Loose Slurry
- Wiresaw
- Coolants
- Cleaners

**SLICE**
- Back-grinding Wheels
- Edge grinding Wheels
- Coolants
- Cleaners

**GRIND**
- Lapping powder
- Lapping slurry
- Prepolish slurry
- Pads
- Cleaners

**LAP**
- Polishing Slurry
- CMP Slurry
- CMP Cleaners
- Pads
- Pad Cleaners

**POLISH & CMP**
Technology advancement follows a distinct path: the Cycle of Capability.
New capability cycles are loosely joined with common equipment and targets

New Processes
New consumables
New equipment
New Processes
New Processes
New Processes
New Processes

New cost targets
New processes
New equipment
New cost targets
New processes
New equipment
New cost targets
New processes

Cycle of Capability
Processes with device impact (cleaning, metrology)
Application knowledge
Particle + Chemistry + Pad

3 new PORs
We challenge our technology processes to evolve in synchrony
An integrated vision for development & manufacturing

- New cost targets
- New consumables
- New equipment
- Processes with device impact (cleaning, metrology)
- Application knowledge

Cycle of Capability

Operational Efficiency

New Processes

New Cost Targets

Coolants & Cleaners

Grinding Wheels

CMP Slurry

New equipment

New Processes

Pad Dynamics

1 new POR

- Particle
- Chemistry
- Application
 Technologies for particle synthesis and manufacture are at our core

**Synthesis from 20 to 2000°C**
- Sol-gel & precipitation
- Electrofusion
- Carbothermal

**Drying and forming technologies**
- Spherical & shape forming
- Slurry & paste mixing

**Crushing, grinding, sizing**
- Dry & wet milling
- Dry and wet classification

**Oxides**
- Boehmite AlOOH
- Transition alumina
- α – alumina
- Zirconia composites
- Stabilized zirconia

**Nitrides**
- Hexagonal BN
- Cubic BN

**Carbon based**
- Silicon carbide (SiC)
- Graphite
- Diamond

**Surface chemistry**
- Dispersion stability
- Lubricant
- Wetting agents

**Surface modification**
- Coupling agent
- Inorganic coating
- Stabilizer

**Formulation**
- Composition
- Microstructure
- Purity, Doping
- Controlled Shape
- Range of Sizes
- Tight/Controlled Size Distribution
- Controlled Porosity
- Surface Treatment

**Expanding core technologies & materials platforms**
Seeded gel - polycrystalline alpha alumina invented in 1984 by SG

Positioned towards fixed abrasives

Initial loose abrasive alpha alumina was about 100-200nm with low control over defectivity (LPC's, fines, and rough morphology)

The material and process technology became better and led to a reduction in LPC's, fines, and improved morphology

In recent years, there is now the capability to drastically improve the defectivity of the alpha alumina

Towards the ultimate alpha alumina particle: sub-100nm, high control over particle defectivity, high chemical resistance

- **CMP applications for alpha alumina**
  - Logic/ Memory devices
  - LED substrates Sapphire
  - Wide bandgap substrates (SiC, GaN)
  - Hard Disk Drive - wafer & disk polishing

- **Abrasive Knobs**
  - Size & distribution
  - Morphology
  - Alpha phase content
  - Surface chemistry
Saint Gobain Zirconia – Offering both hardness and chemical impact

- 180nm
- Core SG process methodology used in microelectronic Logic/Memory finishing applications
- A push for use in SiC and other WBG substrates since 2015 necessitated the need to evolve smaller and more chemically active particles

- 9840-180nm
  - Improved Large Particle Defectivity

- 9840-100nm
  - Improved Chemical Response

- CeO₂ Doped
  - 100 – 200nm with no coarse aggregates
  - Dispersion size close to crystal size

- UD-ZrO₂
  - 35nm dispersion size

- CeO₂ Doped⁺
  - Improved chemical response
We carefully select our chemistry from a mechanistic toolbox and further optimize based on the application.

<table>
<thead>
<tr>
<th>Substrate Type</th>
<th>Surface Oxidation/Hydroxylation (forms a soft layer)</th>
<th>Solubilization of Hydrolyzed Surface (chemical etching)</th>
<th>Particle-Surface Bonding (weakens surface bonds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metals (W, Cu, Al, Ta, ...)</td>
<td>H2O2, KMnO4, Fe(NO3)x, ... to form soft layer of M-O or M-OH.</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Si-based (Si, SiO2, SiC, SiN)</td>
<td>Formation of soft layer of Si-OH.</td>
<td>Formation of Si(OH)4 has solubility in water. C and N solubilizes as gas or ammonium.</td>
<td>Acidity of particle (Ce4+ for example) controls bond strength with Si-O. Hydrolyzed Si-OH reacts with CeO2 particle.</td>
</tr>
<tr>
<td>Oxides/Nitrides (Al2O3, Ga2O3, ZrO2, AlN, GaN, etc.)</td>
<td>KOH on Al2O3 to form soft layer of Al-OH. KMnO4 in water on GaN to form Ga-OH.</td>
<td>---</td>
<td>Potential for particle reactions on oxide substrates to weaken bonds after hydrolysis. Linked to acidity of material. Seen for SiO2 on ZrO2 and enhanced by fluoride.</td>
</tr>
</tbody>
</table>

### Chemical selection examples

- KOH
- KMnO4
- KS2O8
- H2O2
- H5IO6
- HIO3
- Nitrates
- KF
Our SiC slurries are designed around a permanganate base to oxidize (soften) the surface as well as increase solubility (etch)

- Permanganate oxidizes the SiC surface
- Reduction of $+\text{MnO}_4^-$ to $\text{MnO}_4^{2-}$
- Further reduction to $\text{MnO}_2 + \text{OH}^-$
- Formation of soft and high solubility silanol groups at a given pH and CO(g)
- Additional catalysts can be used to further enhance the process
- Dissolution and mechanical abrasion of Si-OH becomes the final removal basis
Building and entire process enables high customization to meet technical targets while maintaining the best cost of ownership.

**SLICE**
- New Premixed Slicing Vehicle
- AmberSlice™ WSS Series Coolant
- AmberCut™ DWC 25 Series Coolant

**GRIND**
- AmberCut 658E Coolant
- AmberSlice™ 202C Coolant

**LAP**
- ClasSiC PS
- SkyRun 2000

**POLISH & CMP**
- ClasSiC 100
- ClasSiC 707
- ClasSiC 102V
- ClasSiC 707X
- AmberClean™ SCA17

Our pre-CMP solutions can be used to set up for the CMP/post-CMP steps.
ClasSiC 707 makes use of a custom developed alumina particle and new catalyst system to be used in batch or single wafer tools

ClasSiC 707 achieves a Material Removal Rate of 5-6 um/hr on batch process and >10 um/hr on single wafer tool

Not all high MRR slurries are the same!
- New generation of engineered particles created for larger diameter wafers
- New catalyst package designed to enhance permanganate effect and double removal rate
- Allows for increase in temperature with low friction to be compatible with all tools
- The ClasSiC 707 package is the state of the art CMP slurry which gives the best cost of ownership profile
Abrasive-free CMP fluids can be used alone or as a final step to achieve a defect and SSD free surface

- ClasSiC 102V is an easy to use fluids for providing a ‘kiss’-finish
- ClasSiC 707X is the state-of-the-art abrasive free slurry making use of proprietary catalyst system – provides excellent surface finish at a more aggressive removal
- These offer a range of removal rates to meet the process and cost needs for any manufacturing facility while still reaching a defect free surface

Both 102V and 707X provide a defect free and SSD free wafer with Ra < 2Å
AmberClean™ is a hassle free cleaner for permanganate-based slurries with a shelf-stable and hazard free formula

AmberClean™ SCA17 is a highly efficient cleaner which degrades permanganate and aids in removing stuck/surface bonded particles

Cleaners improve surface quality and extend system lifetimes

- Shelf-stable formulation means no eventual deactivation and no outgassing/bloating during storage
- Formulated without the use of VOC’s
- Intended to be used for all cleaning needs where ClasSiC slurries come in contact with – wafers, pads, tooling, and factory surroundings
- Can be concentrated up to 3x

Permanganate titration testing example

AmberClean™ SCA17 shown to be up to 20% more efficient with no outgassing or odors during permanganate remediation testing
No process can change alone: an integrated approach to CMP consumable development and manufacturing