

Semicon wide-bandgap and packaging innovation analysis

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In this viewpoint we analyzed semiconductor wide-bandgap manufacturing and semiconductor packaging patents

Methodology for semiconductor wide-bandgap (WBG) and packaging innovation analysis

For our analysis, we first selected relevant semiconductor technology areas:

Wide-bandgap substrates for semiconductor manufacturing (front-end), and **semiconductor packaging for all applications** (back-end).

We subdivided these Categories into specific technology fields of interest and then acquired the corresponding data through professional patent search in global databases. Despite restricting to activities in the last 10 years, the resulting datasets cover more than 60,000 resulting patent applications grouped into almost 34,000 new patent families.

Finally, we used the PATEV Innovation Intelligence system to prepare the vast amount of data for evaluation and interpretation. With the interactive evaluation, data can be presented from different perspectives, such as regional trends, dynamics of applicants, and shifts in technology focus.



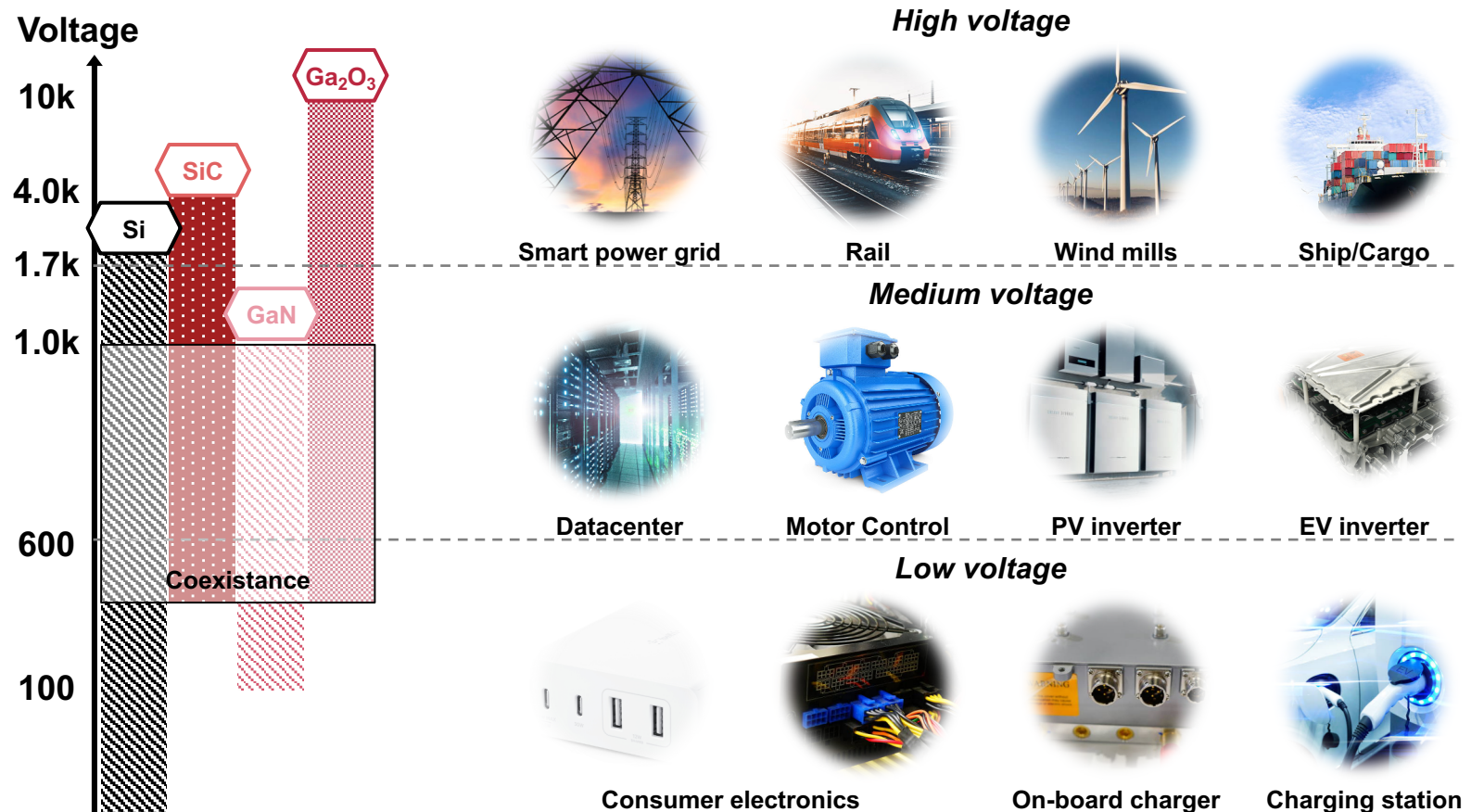
Wide-bandgap power devices allow for higher voltages and temperatures, improved efficiency, and reduced energy loss

Overview of analyzed technologies (I/II) – Wide-bandgap materials

Wide-bandgap power devices

- Wide-bandgap materials, such as SiC or GaN possess a larger bandgap compared to Silicon
- The wider bandgap allows for higher breakdown voltages, enabling power devices with lower on-resistance, leading to reduced power losses and better efficiency
- Moreover, their superior thermal conductivity, enables higher power densities and an enhanced overall performance
- With an even bigger bandgap, Ga_2O_3 may be the next promising material for efficient power applications

Application areas of wide-bandgap materials



Semiconductor packaging (back-end) technologies are rapidly evolving driven by demand for smaller and efficient packages

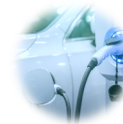
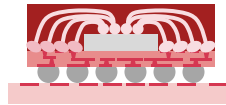
Overview of analyzed technologies (II/II) – Semiconductor packaging

Wide-bandgap power devices

- Semiconductor packaging refers to the process of enclosing and protecting semiconductor chips within a housing, enabling their integration into electronic systems
- Back-end technologies are rapidly evolving and increasing in value-add, driven by the demand for smaller, more efficient packages with an increasing number of functionalities
- Advanced packaging techniques are becoming increasingly important for further miniaturization, particularly as die sizes continue to grow

Semiconductor packaging types and application areas

Wire bonding



Automotive & Transport

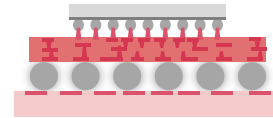


Industrial



Energy & Utilities

Flip-chip



Automotive & Transport



Consumer



Radiofrequency

Wafer-level packaging

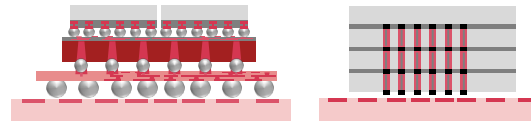


Mobile processors



Radiofrequency

2.5/3D

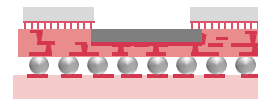


Computing



Mobile processors

Embedded die



Computing



Mobile processors

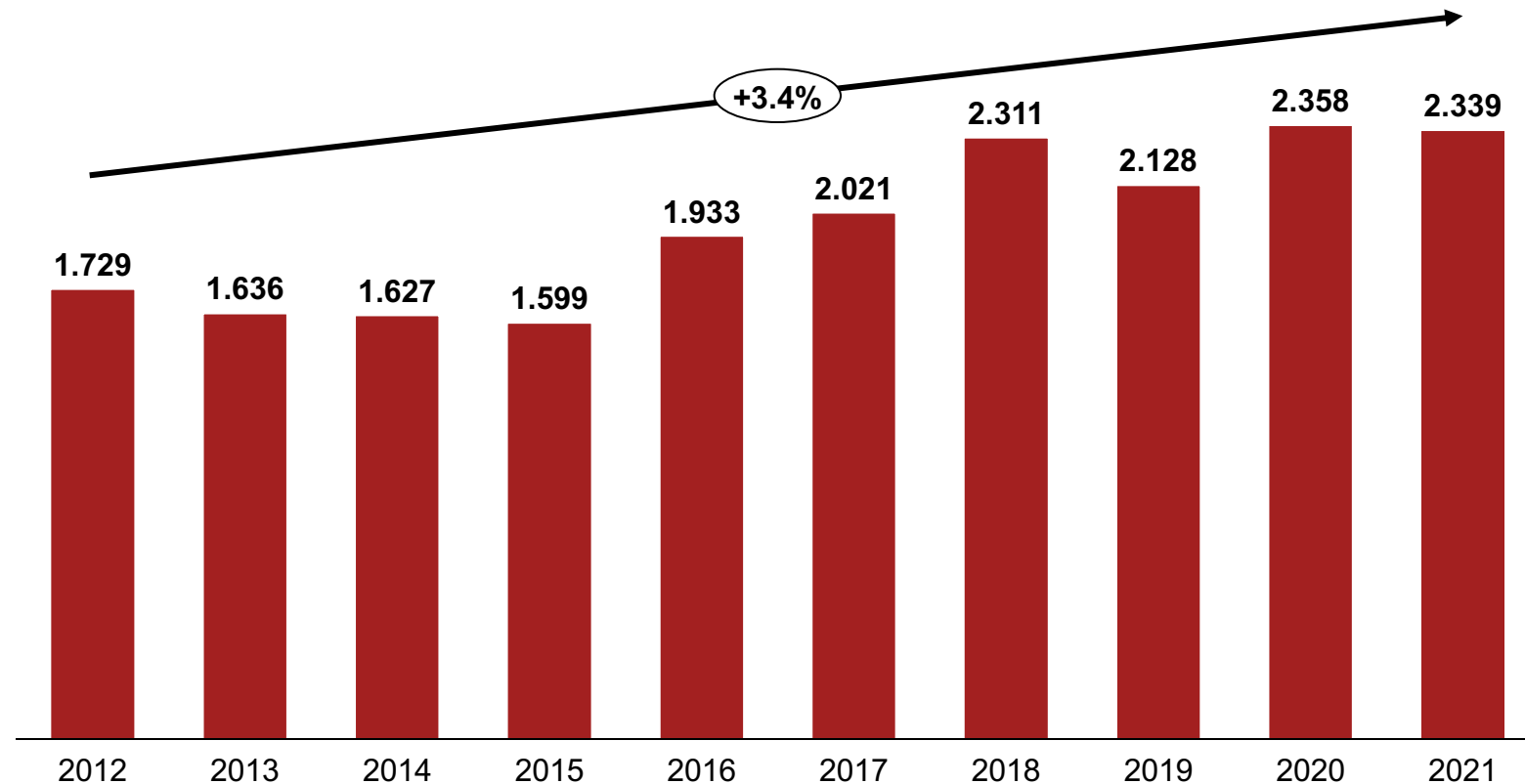
Summary of hypotheses for semiconductor wide-bandgap (front-end) and packaging (back-end) packaging innovation

- 1 Patents fillings for WBG semicons grown at 3.4% since 2012
- 2 China dominates the number of publications for WBG
- 3 Strongly growing interest in Ga_2O_3 substrates
- 4 Japanese IDMs at the top of patent fillings for SiC & GaN
- 5 High impact research from IDMs with focus on automotive
- 6 Packaging patents growing strongly with ~17% since 2015
- 7 Top Asian Foundries and OSATs far ahead in patent volumes
- 8 Western IDMs and foundries innovation drivers in packaging

The number of filled patents in Semicon WBG reached ~2,300 in 2021, growing at a CAGR of ~3.4% since 2012

1 Development of WBG related patent filings

Number of WBG patent filings by year



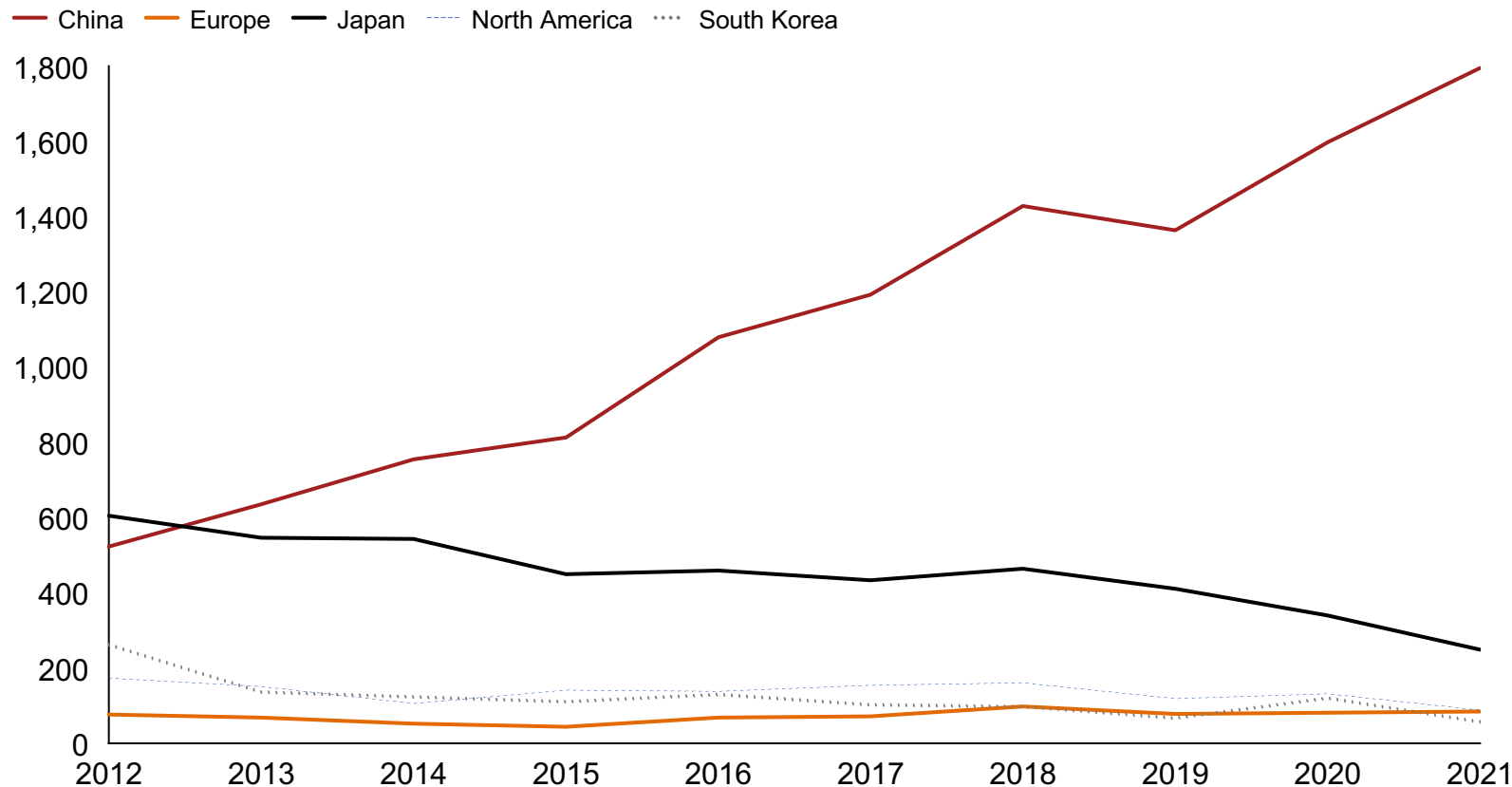
Key takeaways

- Increasing need for efficient power semiconductors driving innovation in WBG
- Over the last 8 years, WBG-related patent filings grown moderately, reaching an all-time high of 2,300 despite the Covid-19 pandemic
- Between 2012 and 2015 a slight decline can be observed, indicating uncertainty in the field
- After 2016, patent filings significantly increased as the SiC technology overcame commercial barriers and first modules were introduced

Gap of WBG patent filings between China and the other regions increasing significantly since 2013

2 Development of WBG related patent filings by region

Number of patent filings by year and region



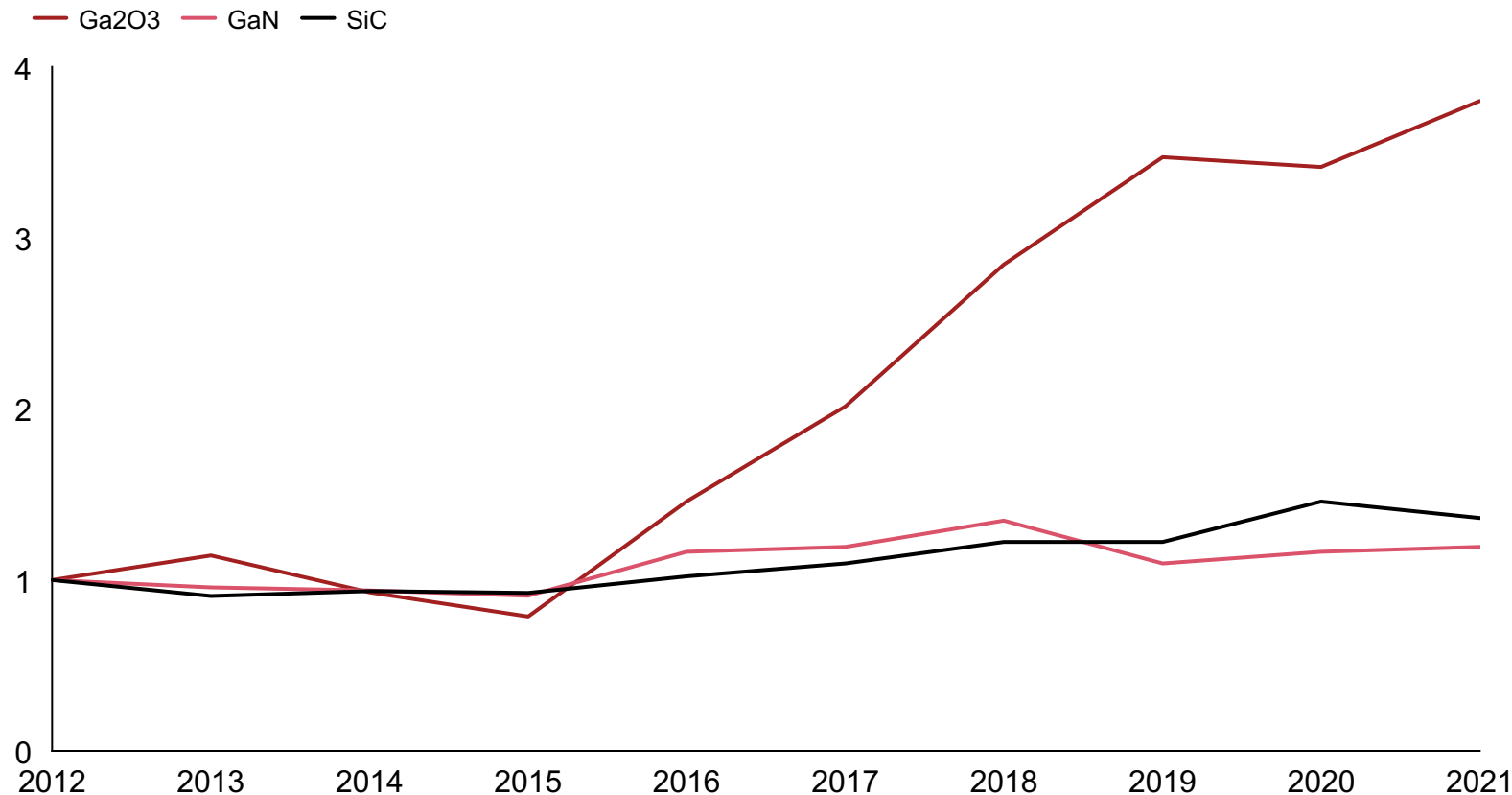
Key takeaways

- China dominated the number of patent filings for WBG semicons growing significantly since 2012
- In 2020, China accounted for 70% of WBG patents led by research institutes and universities
- In contrast, in other regions such as Japan, Europe and North America, patents fluctuate around a constant level or even face declines
- Despite the imbalance Western and Japanese players have a strong position in the WBG market

In contrast to SiC and GaN, Ga₂O₃ patents experienced a strong uptake after 2015 reaching 3-4 times the level of 2012

3 Development of WBG related patent filings by substrate

Ratio of new patents per substrate (normed to level of 2012)



Key takeaways

- Continuous R&D in SiC and GaN power semiconductors and RF devices by the established players is contributing to the steady number of patents in the last six years
- With an even bigger bandgap, Ga₂O₃ may be the next promising material for efficient power applications
- Number of patents for Ga₂O₃ multiplied after 2015 driven by Chinese institutes and Japanese companies such as Tamura, Toyota, Denso and NGK

Japanese semicon and auto players are dominating SiC publications – established IDMs with low focus on Ga₂O₃

4 Development of WBG related patent filings by substrate of major players

Relevant players in WBG patent landscape (I/II)

Companies	SiC	GaN	Ga ₂ O ₃	Total
	Number of patent filings from 2012 to 2020			
 Sumitomo	493	130	7	593
 Fuji Electric	403	63	7	452
 Mitsubishi	299	61	6	342
 Toshiba	222	94	2	308
 Infineon	128	24	1	144
 ROHM	121	34	7	139
 STMicroelectronics	45	11	1	53
 Sanan IC	42	55	1	81
 Wolfspeed	33	12		38
 BYD	28	18		44
 ON Semiconductor	24	24	1	45
 Fujitsu	17	75	2	81
 Intel	12	90	8	103
	1,941	1,523	67	3,292

Key takeaways

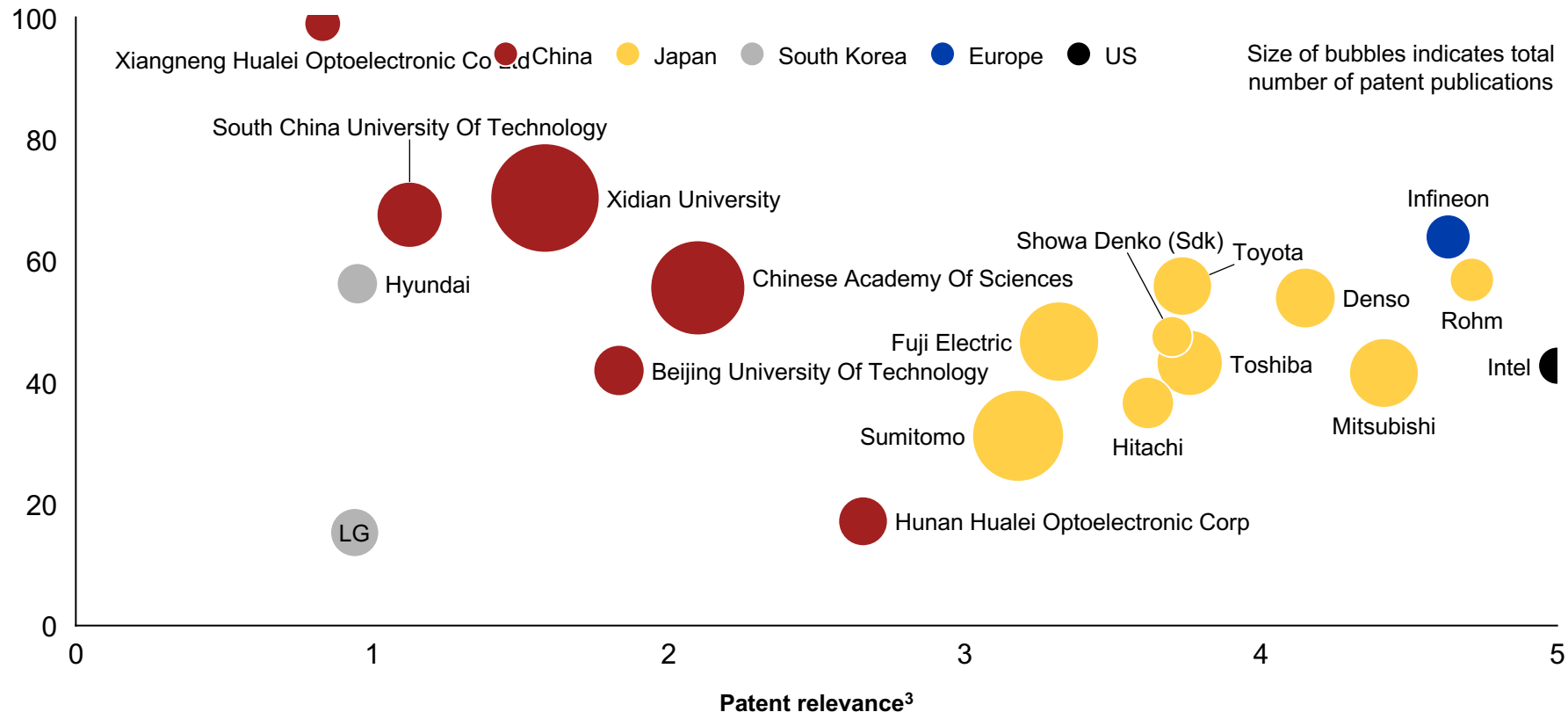
- Japanese IDMs dominate the number of patent filings for SiC power semiconductors
- Intel and Fujitsu are prioritizing GaN research due to their consumer electronics product portfolio
- Established power semiconductor players like STMicro, Infineon, ROHM, and Onsemi have yet to focus on the development of Ga₂O₃

Enterprises file a lower number of WBG patents compared to Chinese universities, but outweigh them in significance

5 WBG patent relevance and innovation speed of major players

Relevant players in WBG patent landscape (II/II)¹

Innovation speed²



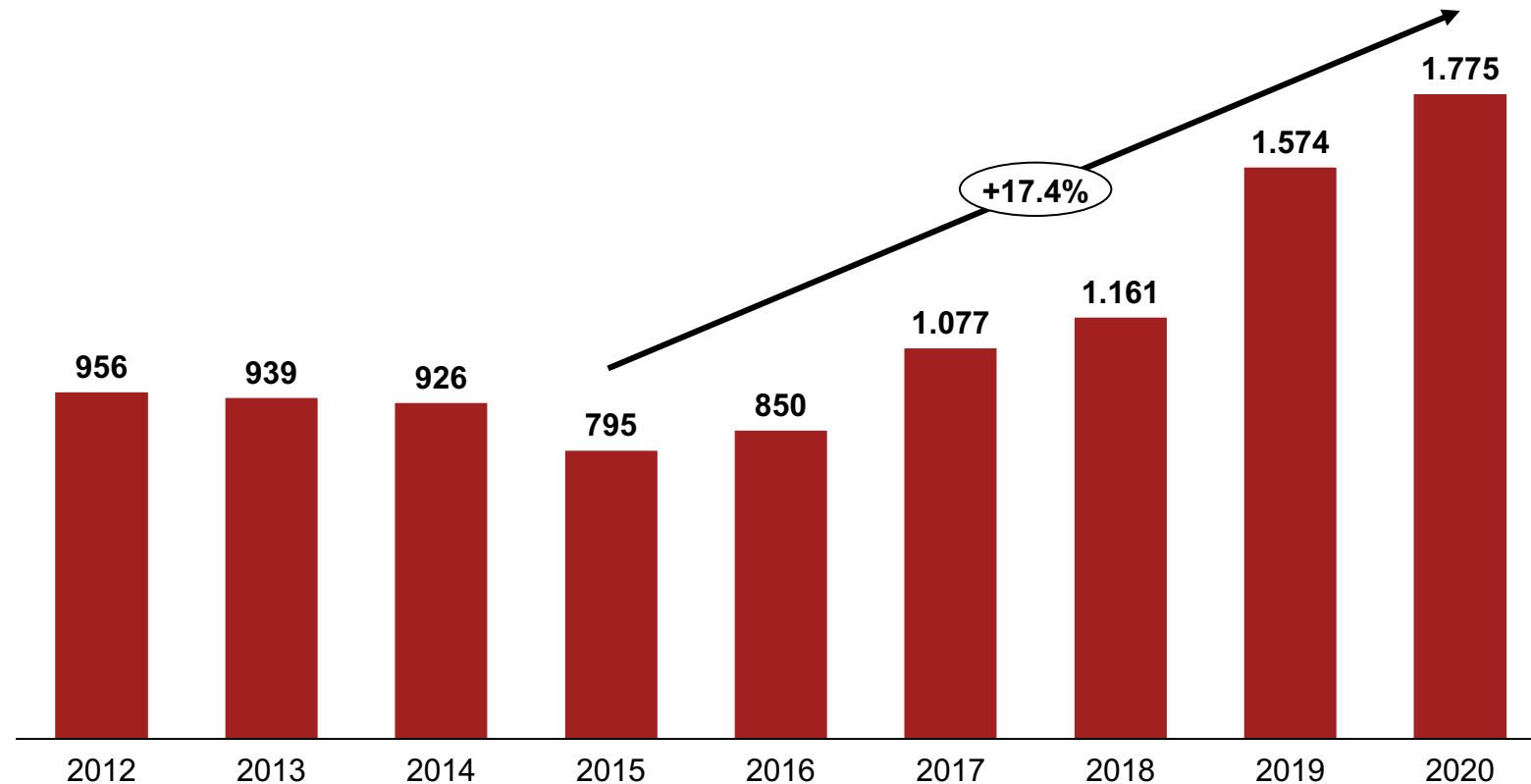
Key takeaways

- Chinese research institutes contribute significantly to the number of WBG publications
- Conversely, patents of substantial relevance primarily originate from power semiconductor IDMs involved in the automotive and transport sectors
- Intel stands out as an exception, with their GaN-related patents holding significant relevance in the consumer electronics domain
- Overall, there is a dearth of new players introducing novel solutions to the market

Patents in semicon packaging have grown with a strong CAGR of above 17% between 2015 and 2020

6 Development of semicon packaging related patent filings

Number of semicon packaging patent filings by year



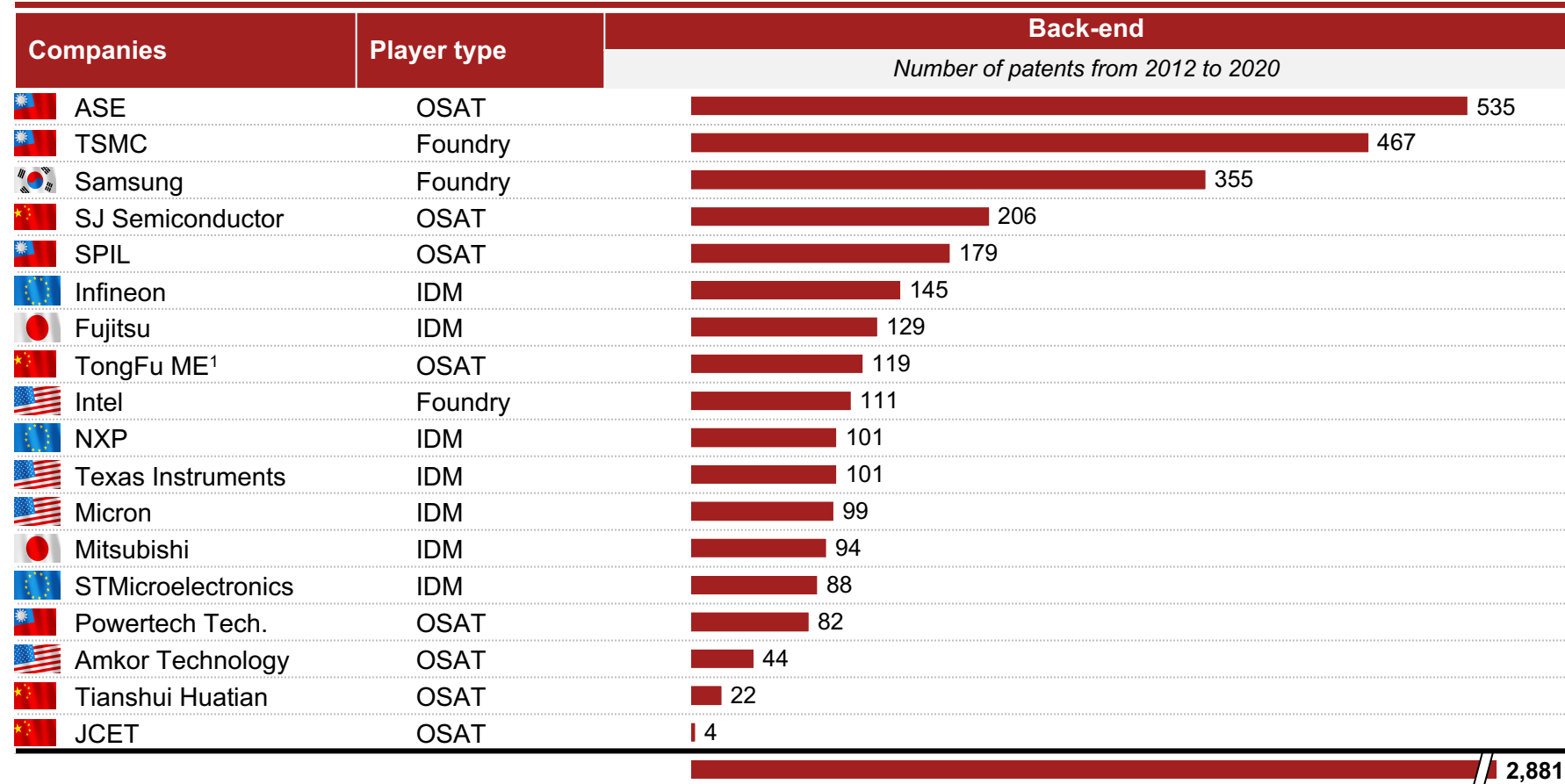
Key takeaways

- The value-add of packaging has increased in the second half of the last decade
- Consequently back-end-related patent filings increased and reached all-time high of 1,775 in 2020
- The strong growth over the last 5 years is driven by the demand for smaller, more efficient packages with an increasing number of functionalities
- Advanced packaging is helping to overcome some of the limitations of traditional packaging approaches

Asian players dominate patent volumes in semicon packaging; Western IDMs a bit behind but still with significant efforts

7 Semicon packaging related patent filings of major players

Relevant players in semicon packaging patent landscape (I/II)



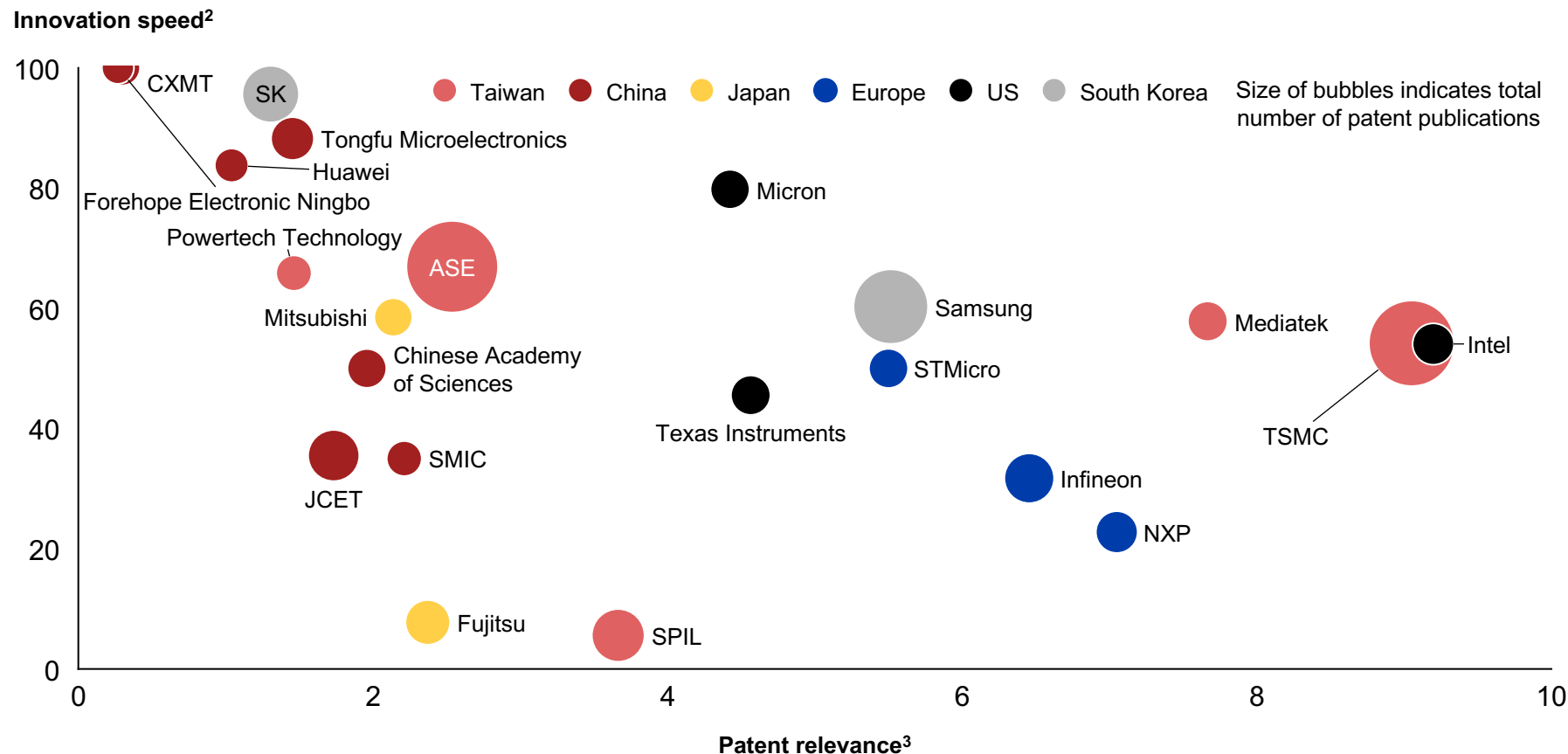
Key takeaways

- Asian foundries and OSATs are dominating the number of patent filings for semicon packaging
- Particularly, ASE, TSMC, and Samsung are making significant investments in packaging research
- Western IDMs such as Infineon, Intel, NXP, TI, and STMicro are aware that innovation in back-end is gaining more relevance and are actively driving research and development in packaging and testing

Major semicon front-end manufacturers also responsible for most impactful research on semiconductor packaging

8 Semicon packaging patent relevance and innovation speed of major players

Relevant players in semicon packaging patent landscape (II/II)¹



Key takeaways

- Despite being responsible for the second highest number of publications, TSMC's patents stand out as some of the most relevant ones in the industry
- Apart from the big foundries and Mediatek, Western IDMs are responsible for the most impactful patent research
- Chinese semiconductor companies excel in swift patent publication rates, but their research has limited impact on industry peers

Contact us for further discussion

PwC Strategy&

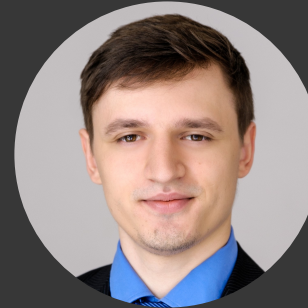
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