# 3D Memory
## Patent Landscape Analysis
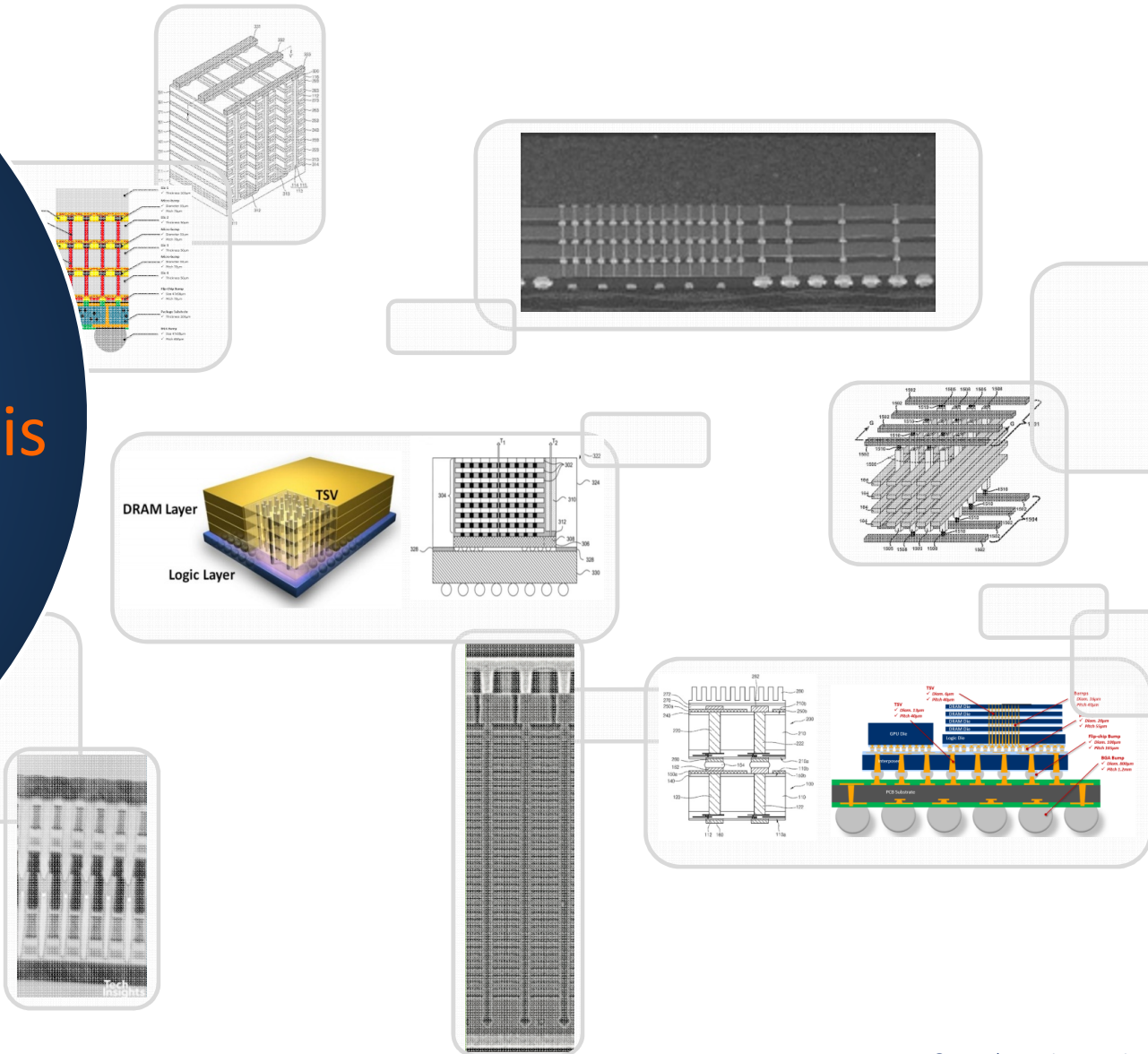
D43D Workshop

June 2017

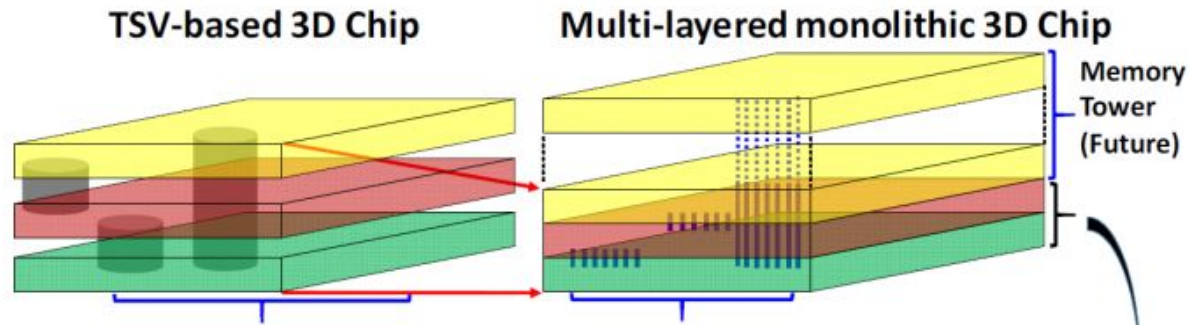Audrey Bastard
*Technology & Patent Analyst*
audrey.bastard@knowmade.fr

DRAM Layer

TSV
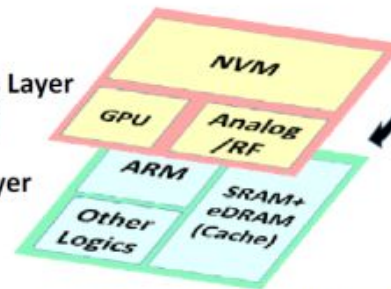
Logic Layer

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Patent & Technology Intelligence

# INTRODUCTION
## 3D Memory



TSV-based 3D Chip

Multi-layered monolithic 3D Chip

Memory Tower (Future)

Through Silicon Via(TSV)

Normal Via(Higher bandwidth)

| | Through Silicon Via (TSV) | Monolithic 3D integration |
|---|---|---|
| Diameter | 2-4 µm | <200 nm |
| Height | 20-50 µm | <300 nm |
| Alignment accuracy | ~1 µm | ~20 nm |
| Reference | ITRS 2012~2015 | This work |

Heterogeneous Layer (Layer 2)

Pure Logic Layer (Layer 1)

NVM

GPU | Analog /RF

ARM

Other Logics | SRAM+ eDRAM (Cache)

3D Monolithic (2013)

*High Bandwidth Memory*

http://www.pcgameshardware.de

*Hybrid Memory Cube*

https://www.golem.de

**1st part of this presentation**
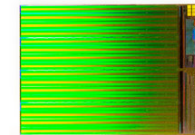
*3D NAND Die*

Micron Website

*3D Cross-Point array ReRAM*
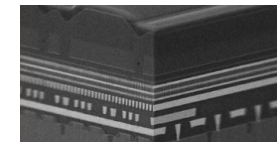
Western Digital, FMS 2016
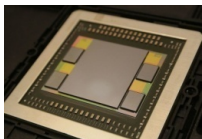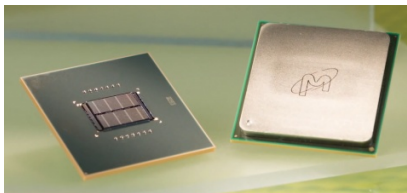
**2nd part of this presentation**

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# INTRODUCTION
## Memory Types
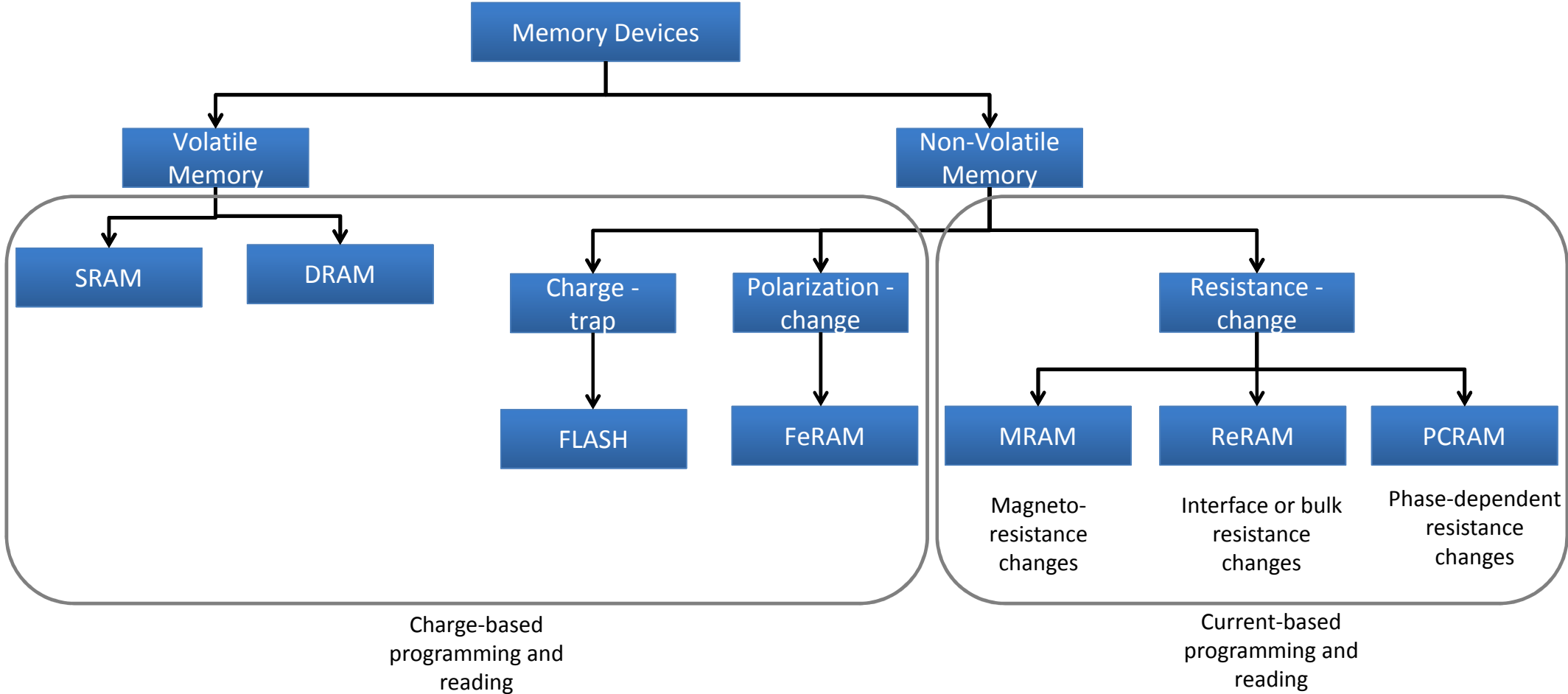
# INTRODUCTION
## Methodology for patent search, selection and analysis
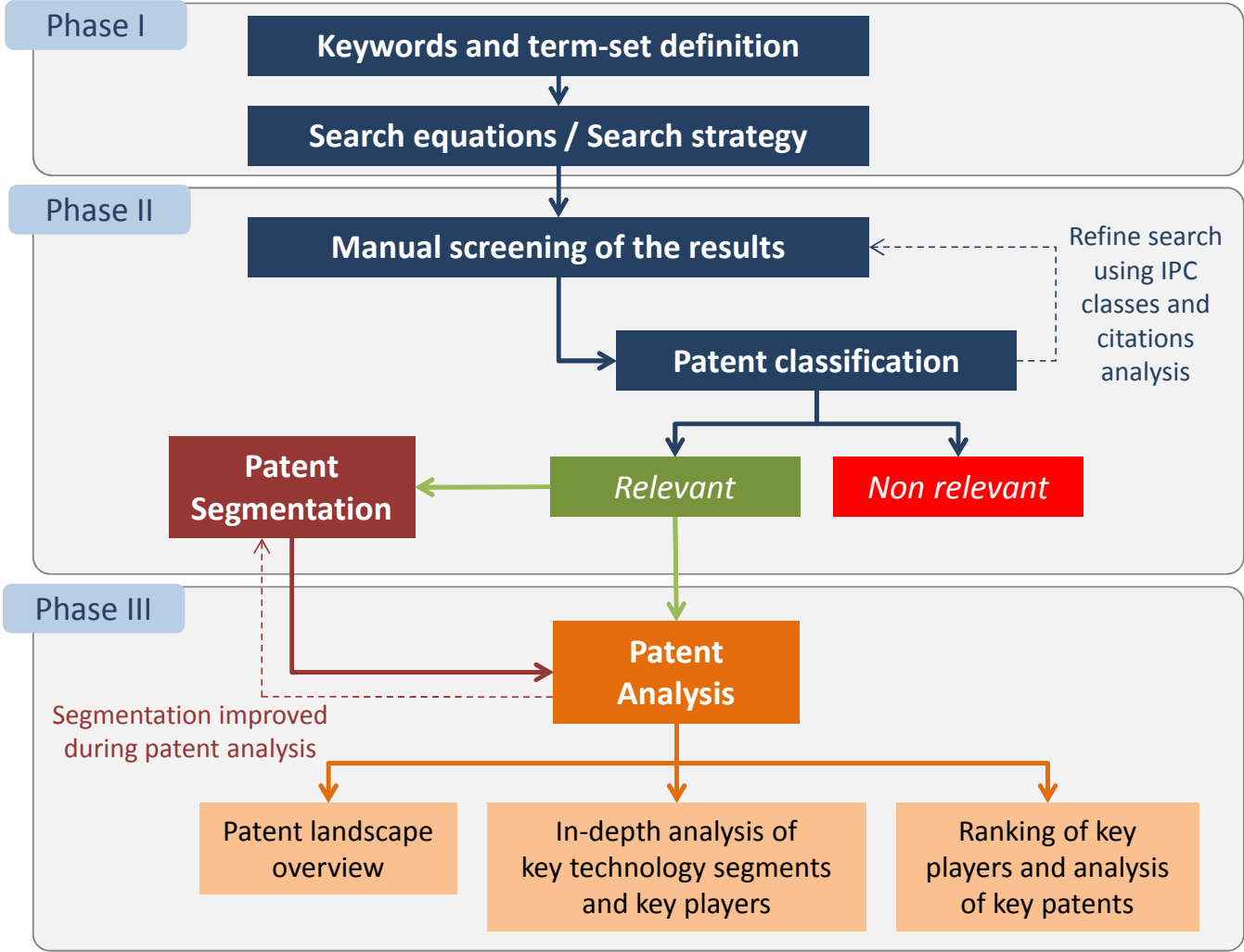
**Phase I**

**Keywords and term-set definition**

**Search equations / Search strategy**

**Phase II**

**Manual screening of the results**

Refine search using IPC classes and citations analysis

**Patent classification**

**Patent Segmentation**

*Relevant*

*Non relevant*

**Phase III**

Segmentation improved during patent analysis

**Patent Analysis**

Patent landscape overview

In-depth analysis of key technology segments and key players

Ranking of key players and analysis of key patents

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# TABLE OF CONTENT
## 3D Memory

TSV Stacked Memory

3D NVM

Conclusion

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# TABLE OF CONTENT
## 3D Memory

# INTRODUCTION
## TSV Stacked Memory Roadmap
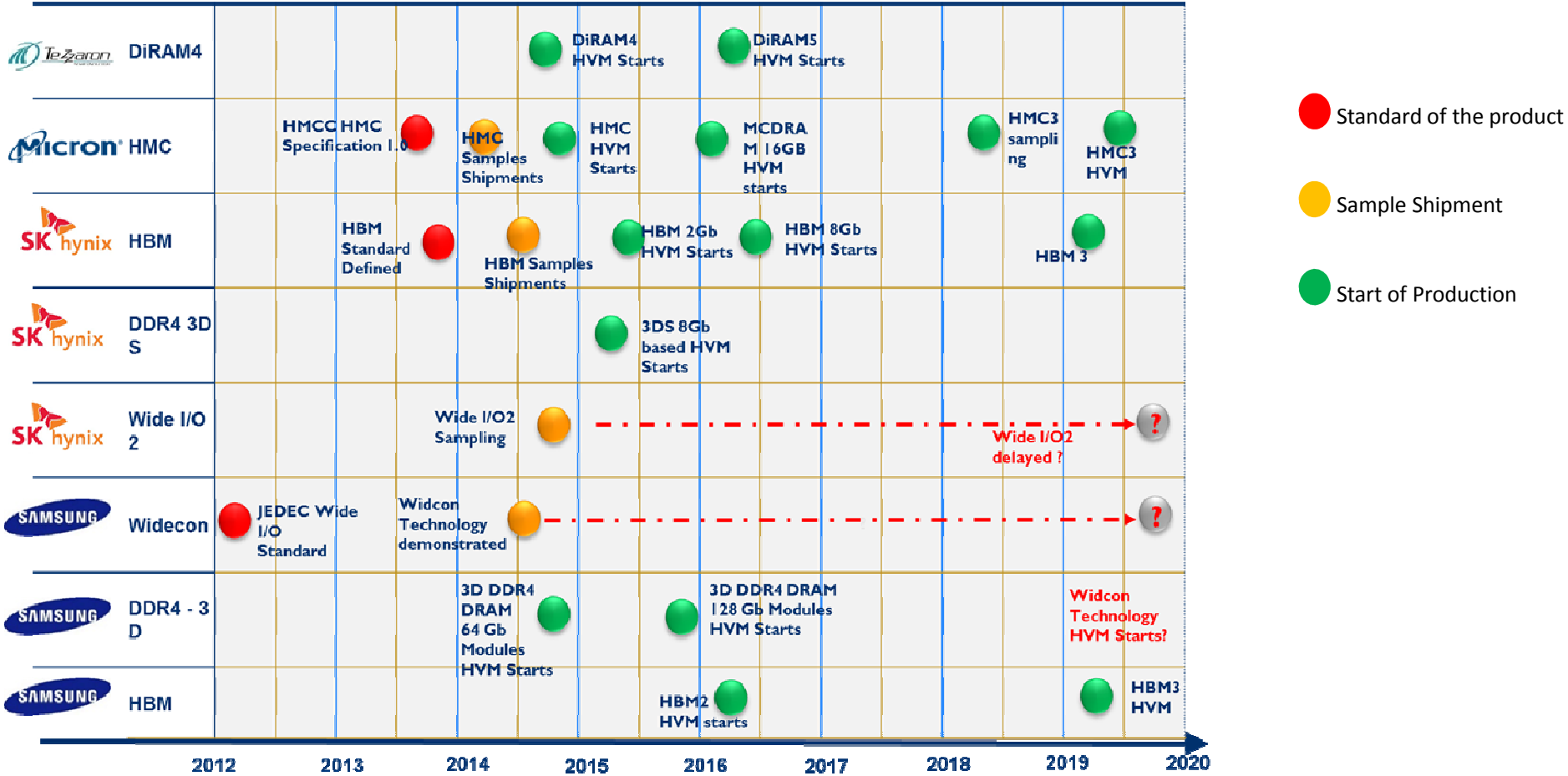
# IP OVERVIEW

## Main patent assignees in TSV stacked memory

**Ranking of main patent assignees
involved in TSV stacked memory**
(according to the number of their patent families*)

*With Elpida's patents*

| Assignee | Value |
|----------|-------|
| SAMSUNG ELECTRONICS (KR) | 100+ |
| SK HYNIX (KR) | 60+ |
| MICRON TECHNOLOGY (US) | 60+ (70+) |
| ELPIDA MEMORY (JP) | 50+ |
| INTEL (US) | 40+ |
| TOSHIBA (JP) | 10+ |
| ADVANCED MICRO DEVICES (US) | <10 |
| HITACHI (JP) | 5 |
| NEC (JP) | 5 |
| RAMBUS (US) | <5 |
| IBM (US) | <5 |
| HEWLETT PACKARD (US) | <5 |
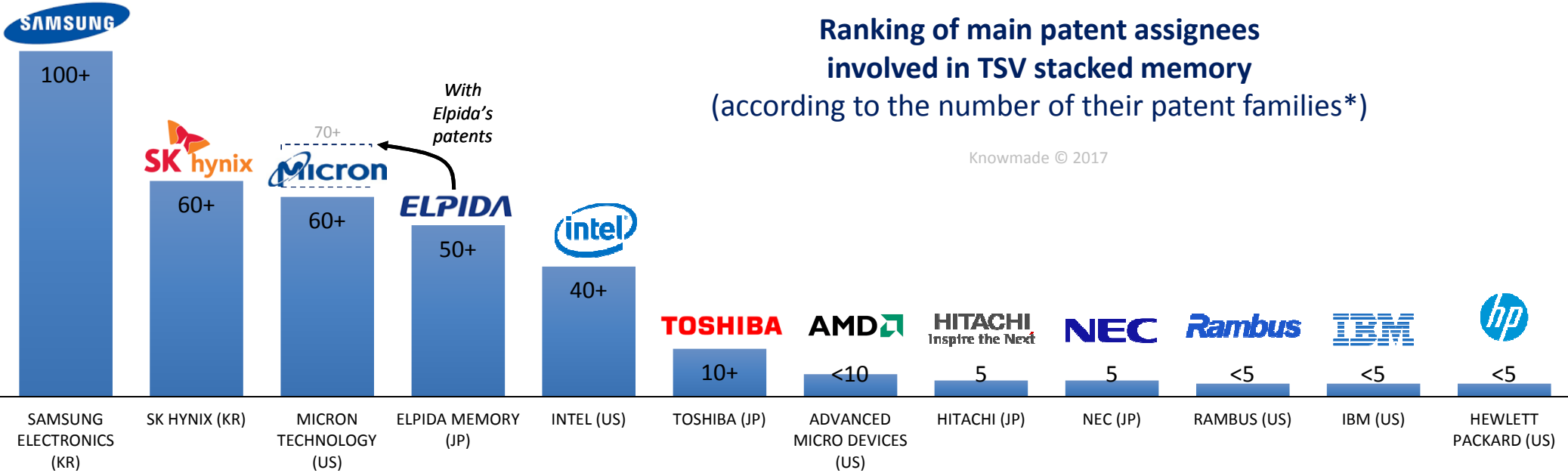
- **Mainly industrial players from USA, Japan and Korea**
- **Micron/Elpida and Samsung own more than 40% of patents together**
- **Most of Elpida's patents were acquired by PS4 Luxco in 2013**
- **R&D Labs** have only few patents (Carnegie Mellon University, University of California, ITRI, ETRI, Hiroshima University)
- **Tezzaron holds 6 patent families on 3-dimensional IC design (not focus on stacked memory)**

\* A patent family is a set of patents filed in multiple countries to protect a single invention by a common inventor. A first application is made in one country – the priority country – and is then extended to other countries.

# PATENT LANDSCAPE OVERVIEW

## Time evolution of patent publications in TSV stacked memory

**Patenting activity in TSV stacked memory**

*1,500+ patents grouped in 400+ patent families**

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**IBM**
US5099309
Three-dimensional memory card structure with internal direct chip attachment

Legend:
- Samsung
- SK Hynix
- Micron
- Elpida
- Intel
- Toshiba
- Other Assignees

**6.4%** CAGR 2005-2012

Number of publications (Y-axis: 0 to 70)

Data points by Earliest Publication Year of Each Patent Family:
1991: 1
1994: 1
1995: 2
1996: 1
1998: 1
2000: 2
2001: 4
2002: 3
2003: 2
2004: 4
2005: 12
2006: 7
2007: 16
2008: 25
2009: 34
2010: 44
2011: 52
2012: 57
2013: 53
2014: 40
2015: 42
2016: 28

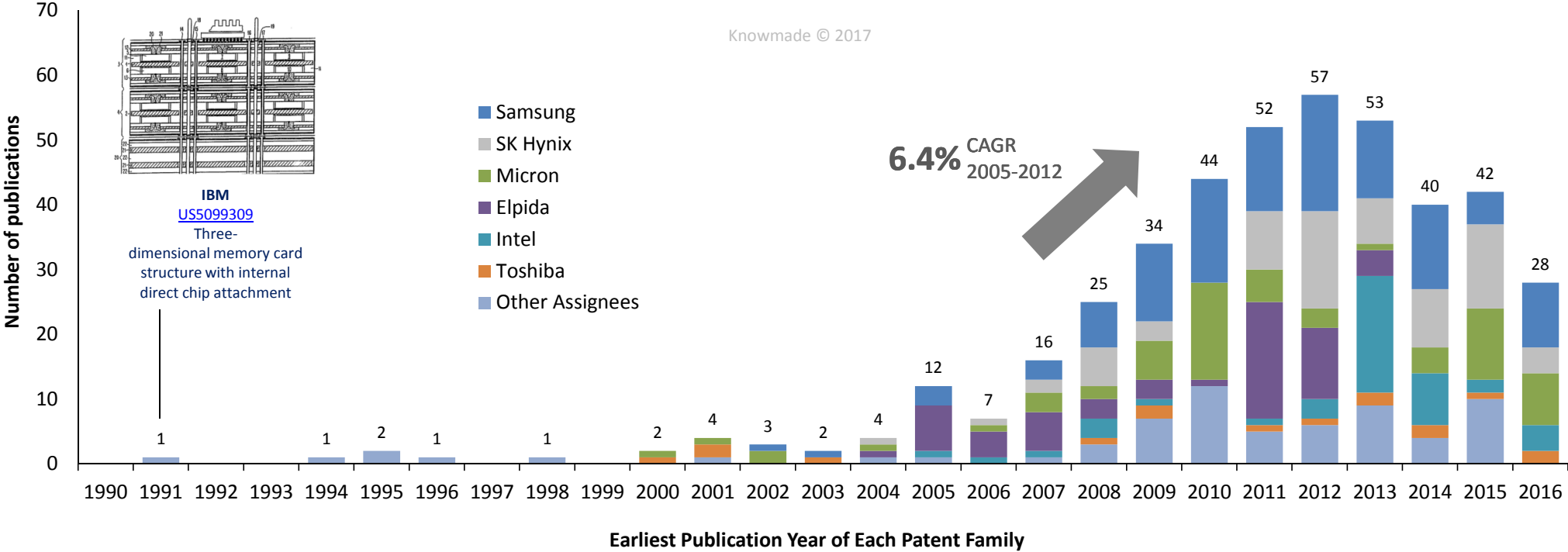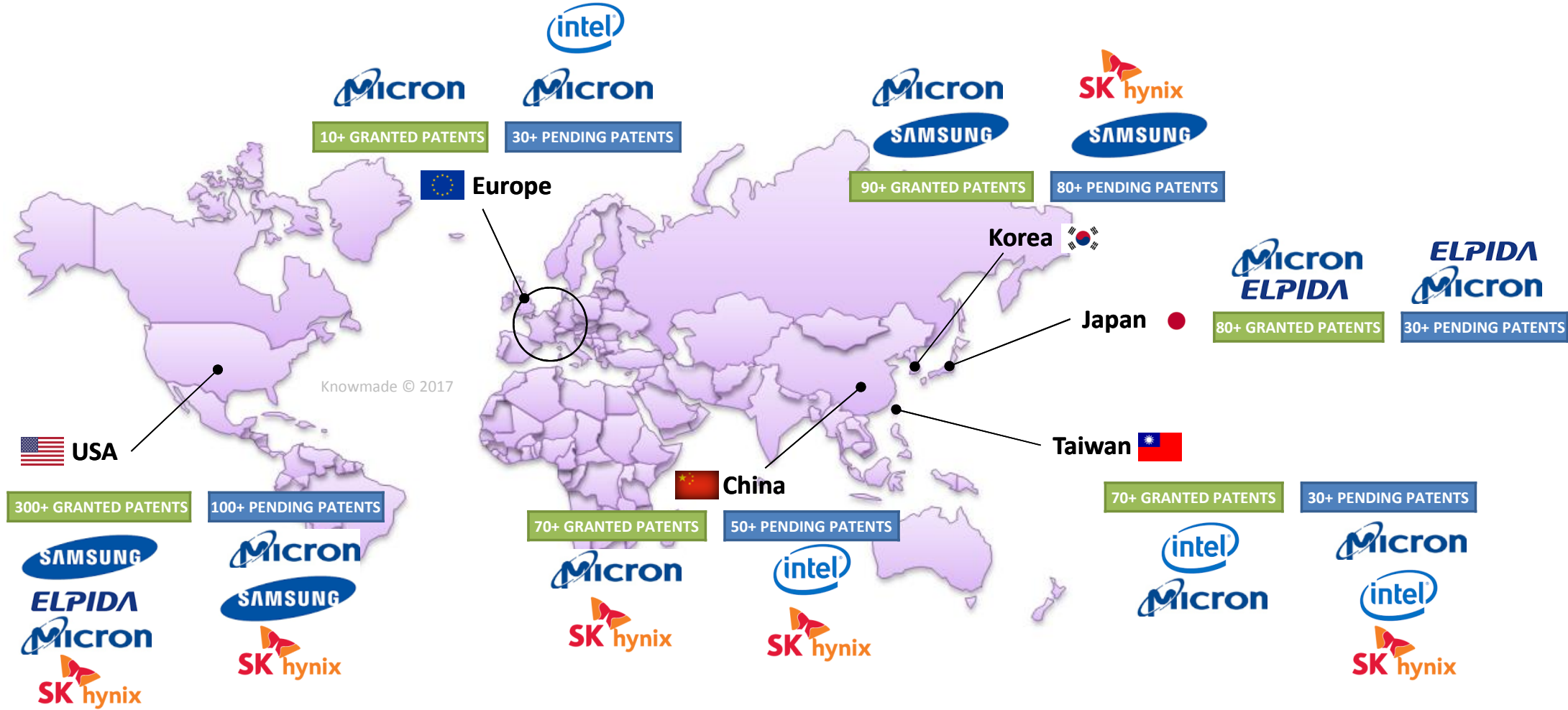**Earliest Publication Year of Each Patent Family**

* A patent family is a set of patents filed in multiple countries to protect a single invention by a common inventor.
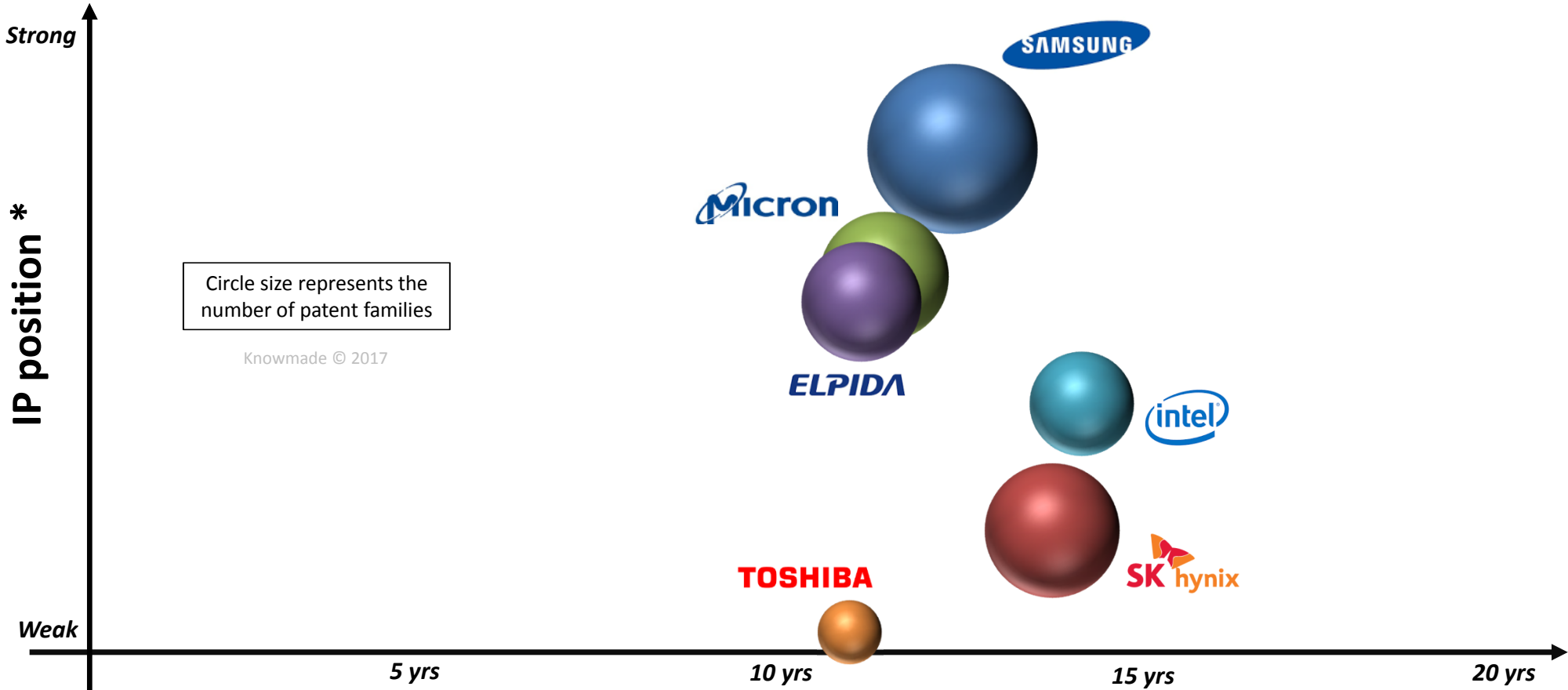A first application is made in one country – the priority country – and is then extended to other countries.

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# PATENT LANDSCAPE OVERVIEW

Geographic map of patenting activity of main IP players involved in TSV stacked memory



intel

**Micron**
10+ GRANTED PATENTS

**Micron**
30+ PENDING PATENTS

**Europe**

**Micron**
**SAMSUNG**
90+ GRANTED PATENTS

**SK hynix**
**SAMSUNG**
80+ PENDING PATENTS

**Korea**

**Japan**

**Micron ELPIDA**
80+ GRANTED PATENTS

**ELPIDA Micron**
30+ PENDING PATENTS

**USA**

**China**

**Taiwan**

300+ GRANTED PATENTS
100+ PENDING PATENTS

70+ GRANTED PATENTS
50+ PENDING PATENTS

70+ GRANTED PATENTS
30+ PENDING PATENTS

**SAMSUNG**
**ELPIDA**
**Micron**
**SK hynix**

**Micron**
**SAMSUNG**
**SK hynix**

**Micron**
**SK hynix**

**intel**
**SK hynix**

**intel**
**Micron**
**intel**
**SK hynix**

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# IP POSITION OF MAIN PATENT ASSIGNEES

## IP position vs. remaining lifetime of enforceable patents



Circle size represents the number of patent families

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**IP position \***

Strong

Weak

**Remaining lifetime of granted patents**
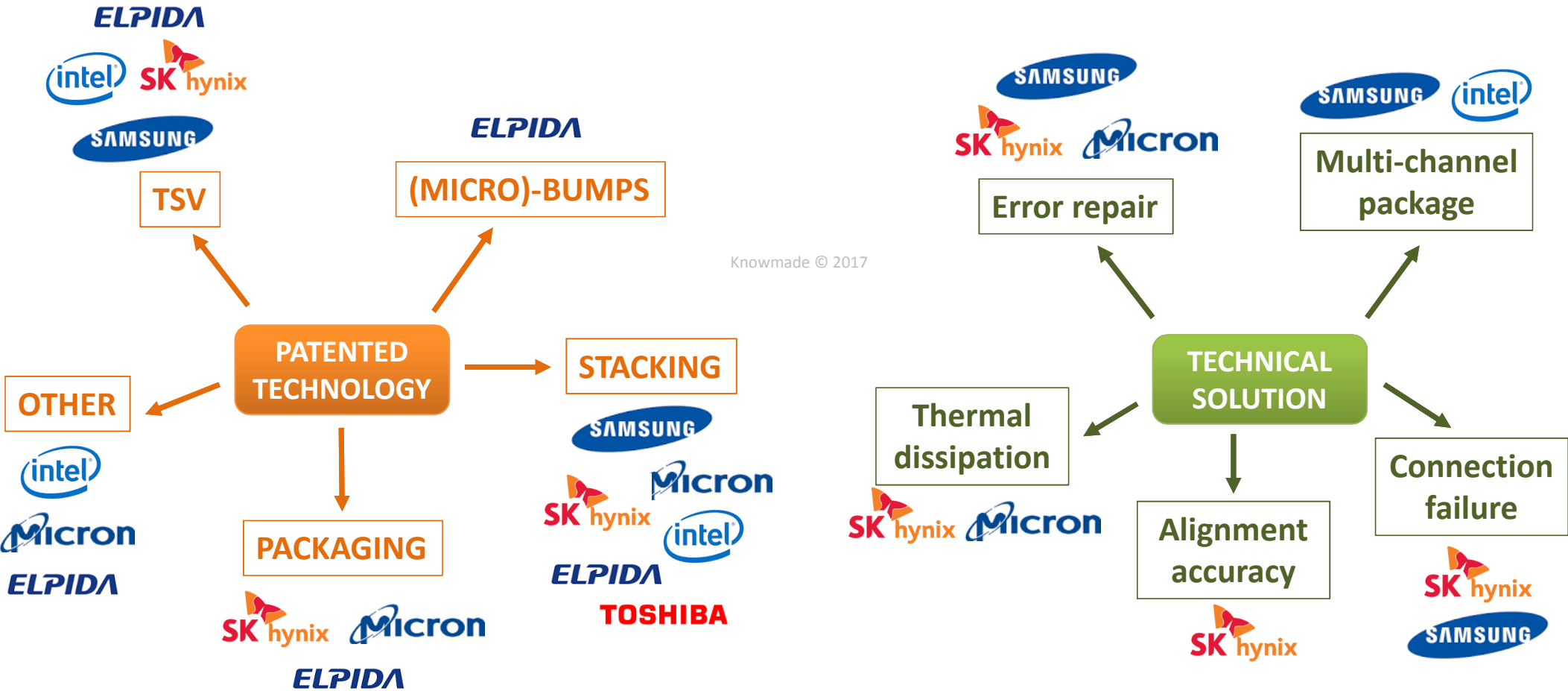
5 yrs    10 yrs    15 yrs    20 yrs

*Indicators: number of granted patents, number of pending patent applications, geographical coverage, IP strategy, IP leadership, IP strength, IP blocking potential

# PATENT SEGMENTATION

Technologies patented by key IP players in TSV stacked memory
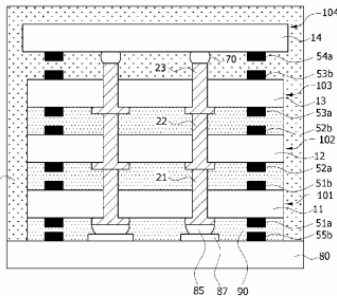
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# TECHNOLOGY OVERVIEW
## Technologies patented by key IP player in TSV stacked memory

**Patented technologies used in SK Hynix HBM's package**
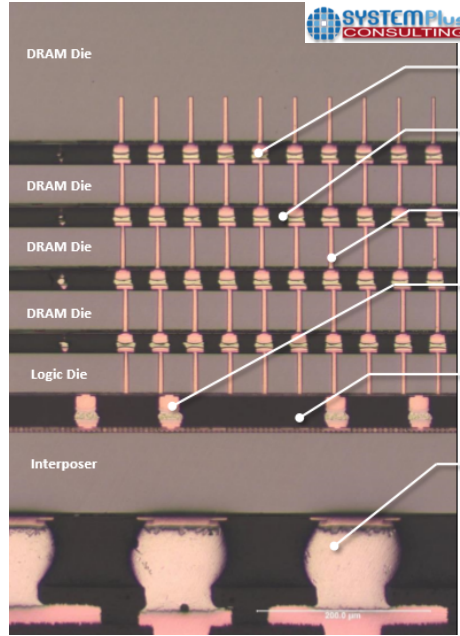**The 4 DRAM dies are connected together with TSV & micro-bumps**

**US8592952** (2013)
Reduce misalignment between chips
→ magnetic force applied between the align patterns

**US9390997** (2015)
Connection electrodes 160 and 162 (front bumps and rear bumps)
→formed of any one of solder, nickel, copper, tin and alloy thereof
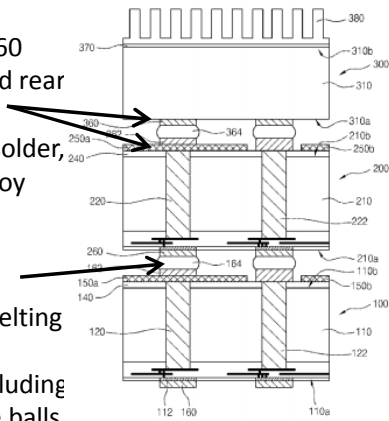
Connection member 164
→ solder having a low melting point or an anisotropic conductive film (ACF) including resin and fine conductive balls



**Micro-bump**
✓ Diameter 16μm
✓ Pitch 40μm

**Underfill**
✓ Thickness 19μm

**TSV**
✓ Diameter 6μm
✓ Depth 46.5μm
✓ Pitch 40μm

**Micro-bump**
✓ Diameter 20μm
✓ Pitch 55μm

**Underfill**
✓ Thickness 33μm

**Flip-Chip Bump**
✓ Size 100μm
✓ Pitch 200μm

*HBM Package Cross Section, SEM View, System Plus Consulting*
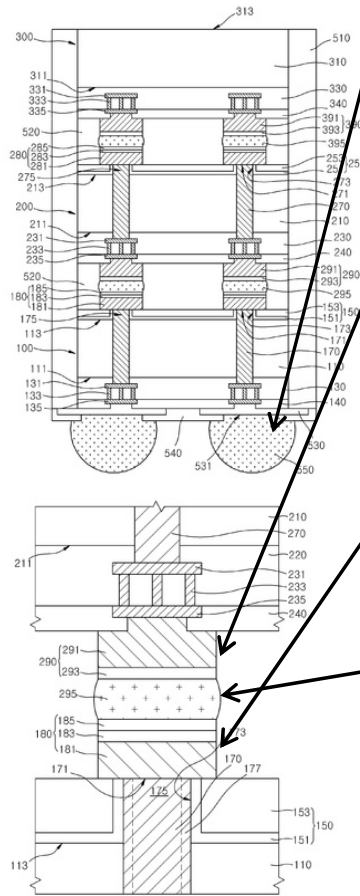
**US9257413** (2015)
Outer connection terminals 550
→plurality of solder balls 2D arrayed.
→ area of a surface on which the outer connection terminals are arrayed can be maximized (even though a width of the lower semiconductor chip is reduced)

Intermediate front side bumps 290
→ front side bump body 291 (Cu) contacting the chip contact portion 235
→ wetting layer 293 (Ni) stacked on the front side bump body 291.

Lower backside bumps 180
→Include also oxidation resistant layer 185(Au)

Conductive adhesives 295 (solder layers)
→disposed on the respective wetting layers 293
→combined with the lower backside bumps

# CONCLUSION

## Patent Landscape analysis
## TSV Stacked Memory

| Top-5 patent assignees | SAMSUNG | MICRON ELPIDA | SK hynix | TOSHIBA | intel |
|---|---|---|---|---|---|
| **IP position** | Very Strong | Strong | Low | Very Low | Medium |
| **Main countries of patent filings** | USA Korea | Worldwide | USA | USA Japan | USA Taiwan |
| **Main patented technology** | Control of the stack, Wafer to wafer technique | Memory technology improvement, Interconnection stacking | Stacking Issues: dissipation, adhesion,… | Stacking Issues | Method for accessing memory, Thinner package substrates |
| **Main technical issues in patents** | Connection Failure Multi-Channel Package Error Repair | Thermal Dissipation Error Repair | Alignment Accuracy Error Repair Thermal Dissipation Connection Failure | Alignment Accuracy Connection Failure | Multi-Channel Package Alignment Accuracy |
| **Products** | 3D DDR4 DRAM production in 2014, HBM2 4Gb and 8Gb in 2016 | Production of 16Gb HMC Gen2 in 2014 with Intel | Production of HBM1 2Gb in 2014, Production of 3DS DDR4 8Gb and Wide I/O2 in 2015, Production of HBM2 4Gb and 8Gb in 2016  HBM3 in 2020 | In 2017/2018, 1To package of 16 NAND dies TSV stacked  2To package will be proposed in 2019 | Production of 16Gb HMC Gen2 in 2014 with Micron |
| **Patent litigations** | Nov-2014 ELM 3D as plaintiff for patent infringement against Samsung Final Decision in Q2 2017 | Nov-2014 ELM 3D as plaintiff for patent infringement against Micron Final Decision in Q2 2017 | Nov-2014 ELM 3D as plaintiff for patent infringement against SK Hynix Final Decision in Q2 2017 | No | No |

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# TABLE OF CONTENT
## 3D Memory

# INTRODUCTION
## 3D NVM Roadmap



| | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|
| **SAMSUNG** | 3D V-NAND | 32L | 48L | 64L | 128L | | 256L/Stack |
| **SK hynix** | | 3D NAND | 36L (V2) | 48L (V3) | 72L (V4) | 128L | 256L |
| **TOSHIBA / Western Digital** | | 3D NAND | 48L | 64L | 96L or 128L | | 256L |
| | | | | | 3D ReRAM? | | |
| **Micron / im FLASH TECHNOLOGIES / intel** | | 3D NAND | 32L (Gen1) | 64L (Gen2) | 128L (Gen3) | | 256L |
| | | | 3D Xpoint (Optane/Intel, QuantX/Micron) | | | | |
| **MXIC** | | | | | 3D NAND ? | L ? | |

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# IP OVERVIEW
## Main patent assignees in 3D NVM

**Ranking of main patent assignees involved in 3D NVM**
(according to the number of their patent families*)

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Bar chart values:
- SANDISK (US): 800+
- SAMSUNG ELECTRONICS (KR): 750+
- TOSHIBA (JP): 700
- SK HYNIX (KR): 350+
- MACRONIX INTERNATIONAL (TW): 210+
- MICRON TECHNOLOGY (US): 150+
- INTEL (US): 30+
- SEOUL NATIONAL UNIVERSITY (KR): 30
- UNITY SEMICONDUCTOR (US): 30
- MATRIX SEMICONDUCTOR (US): 20

- **Mainly industrial players from USA, Korea, Japan and Taiwan**
- **Top 3: SanDisk/Western Digital, Samsung and Toshiba own more than 65% of patents together**
- **Western Digital** acquired **SanDisk** in 2016
- **R&D Labs** have only few patents (Seoul National University)
- **Rambus** acquired **Unity Semiconductor** in 2012
- **SanDisk** acquired **Matrix Semiconductor** in 2005

* A patent family is a set of patents filed in multiple countries to protect a single invention by a common inventor. A first application is made in one country – the priority country – and is then extended to other countries.

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# IP OVERVIEW

## Time evolution of patent publications in 3D NVM
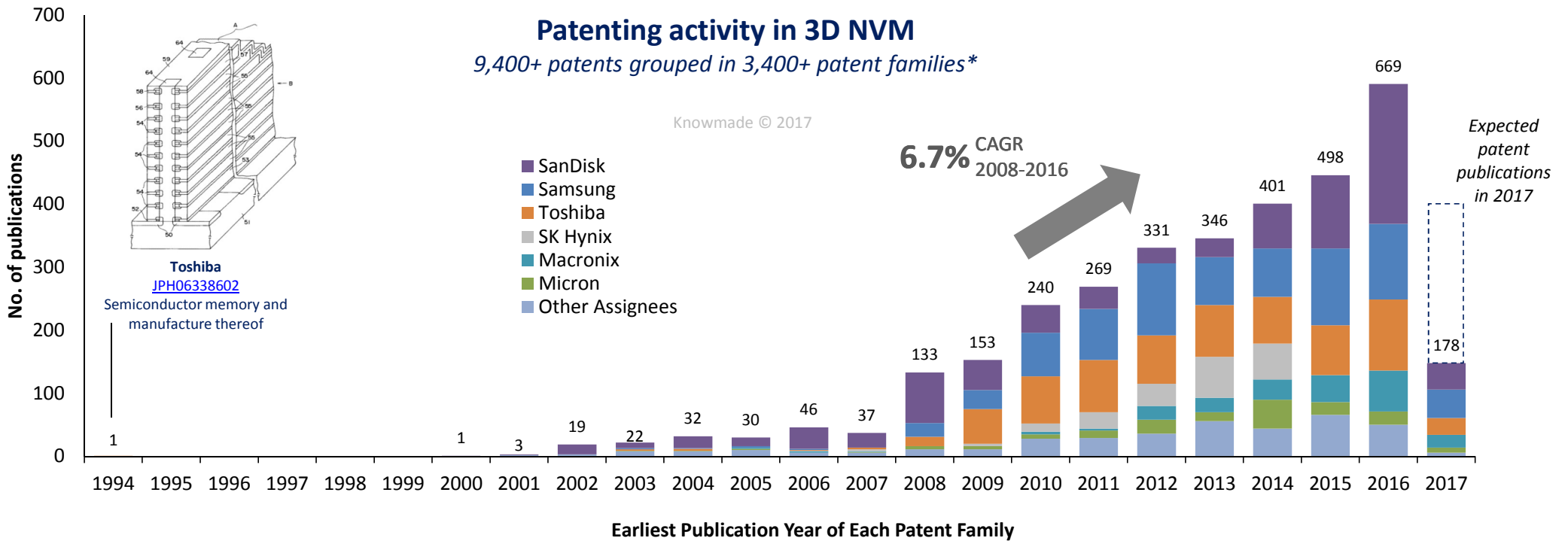


**Patenting activity in 3D NVM**

*9,400+ patents grouped in 3,400+ patent families\**

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**6.7%** CAGR 2008-2016

Legend:
- ■ SanDisk
- ■ Samsung
- ■ Toshiba
- ■ SK Hynix
- ■ Macronix
- ■ Micron
- ■ Other Assignees

Toshiba
JPH06338602
Semiconductor memory and manufacture thereof

Y-axis: No. of publications (0–700)

X-axis: Earliest Publication Year of Each Patent Family

Values by year: 1994: 1, 2000: 1, 2001: 3, 2002: 19, 2003: 22, 2004: 32, 2005: 30, 2006: 46, 2007: 37, 2008: 133, 2009: 153, 2010: 240, 2011: 269, 2012: 331, 2013: 346, 2014: 401, 2015: 498, 2016: 669, 2017: 178

*Expected patent publications in 2017*

**Note**: The patent search was done in June 2017, thus the data corresponding to the year 2017 are not complete. At the time of the patent search, 178 patent families had been published in 2017.

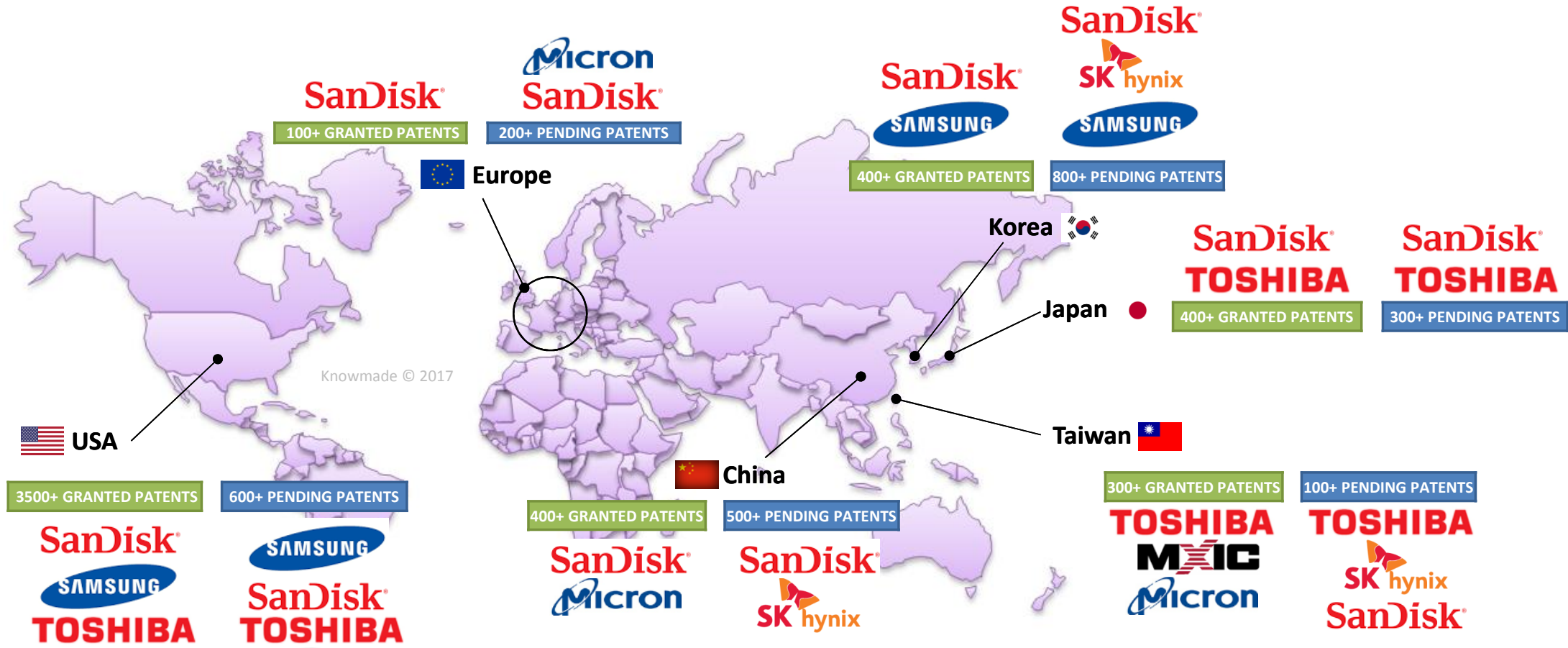\* A patent family is a set of patents filed in multiple countries to protect a single invention by a common inventor.
A first application is made in one country – the priority country – and is then extended to other countries.

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# IP OVERVIEW

Geographic map of patenting activity of main IP players involved in 3D NVM



100+ GRANTED PATENTS
**SanDisk**

200+ PENDING PATENTS
**Micron**
**SanDisk**

**Europe**

400+ GRANTED PATENTS
**SanDisk**
**SAMSUNG**

800+ PENDING PATENTS
**SanDisk**
**SK hynix**
**SAMSUNG**

**Korea**

**Japan**

400+ GRANTED PATENTS
**SanDisk**
**TOSHIBA**

300+ PENDING PATENTS
**SanDisk**
**TOSHIBA**

**Taiwan**

**USA**

**China**

3500+ GRANTED PATENTS
**SanDisk**
**SAMSUNG**
**TOSHIBA**

600+ PENDING PATENTS
**SAMSUNG**
**SanDisk**
**TOSHIBA**

400+ GRANTED PATENTS
**SanDisk**
**Micron**

500+ PENDING PATENTS
**SanDisk**
**SK hynix**

300+ GRANTED PATENTS
**TOSHIBA**
**MXIC**
**Micron**

100+ PENDING PATENTS
**TOSHIBA**
**SK hynix**
**SanDisk**

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# IP POSITION OF MAIN PATENT ASSIGNEES

## IP position vs. remaining lifetime of enforceable patents



Circle size represents the number of patent families

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**IP position \***

*Strong*

*Weak*

5 yrs    10 yrs    15 yrs    20 yrs

**Remaining lifetime of granted patents**

\*Indicators: number of granted patents, number of pending patent applications, geographical coverage, IP strategy, IP leadership, IP strength, IP blocking potential

# PATENT SEGMENTATION

## Memory types timeline of publication in 3D NVM

**Patenting activity in 3D monolithic memory**

*9,400+ patents grouped in 3,400+ patent families\**

**Toshiba**
JPH06338602
Semiconductor memory and manufacture thereof

Legend:
- Flash
- MRAM
- PCRAM
- ReRAM
- General
- Others

**6.7%** CAGR 2008-2016

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*Expected patent publications in 2017*

No. of publications

| Year | Value |
|------|-------|
| 1994 | 1 |
| 2000 | 1 |
| 2001 | 3 |
| 2002 | 19 |
| 2003 | 22 |
| 2004 | 32 |
| 2005 | 30 |
| 2006 | 46 |
| 2007 | 37 |
| 2008 | 133 |
| 2009 | 153 |
| 2010 | 240 |
| 2011 | 269 |
| 2012 | 331 |
| 2013 | 346 |
| 2014 | 401 |
| 2015 | 498 |
| 2016 | 669 |
| 2017 | 178 |

**Earliest Publication Year of Each Patent Family**

<u>Note</u>: The patent search was done in June 2017, thus the data corresponding to the year 2017 are not complete. At the time of the patent search, 178 patent families had been published in 2017.
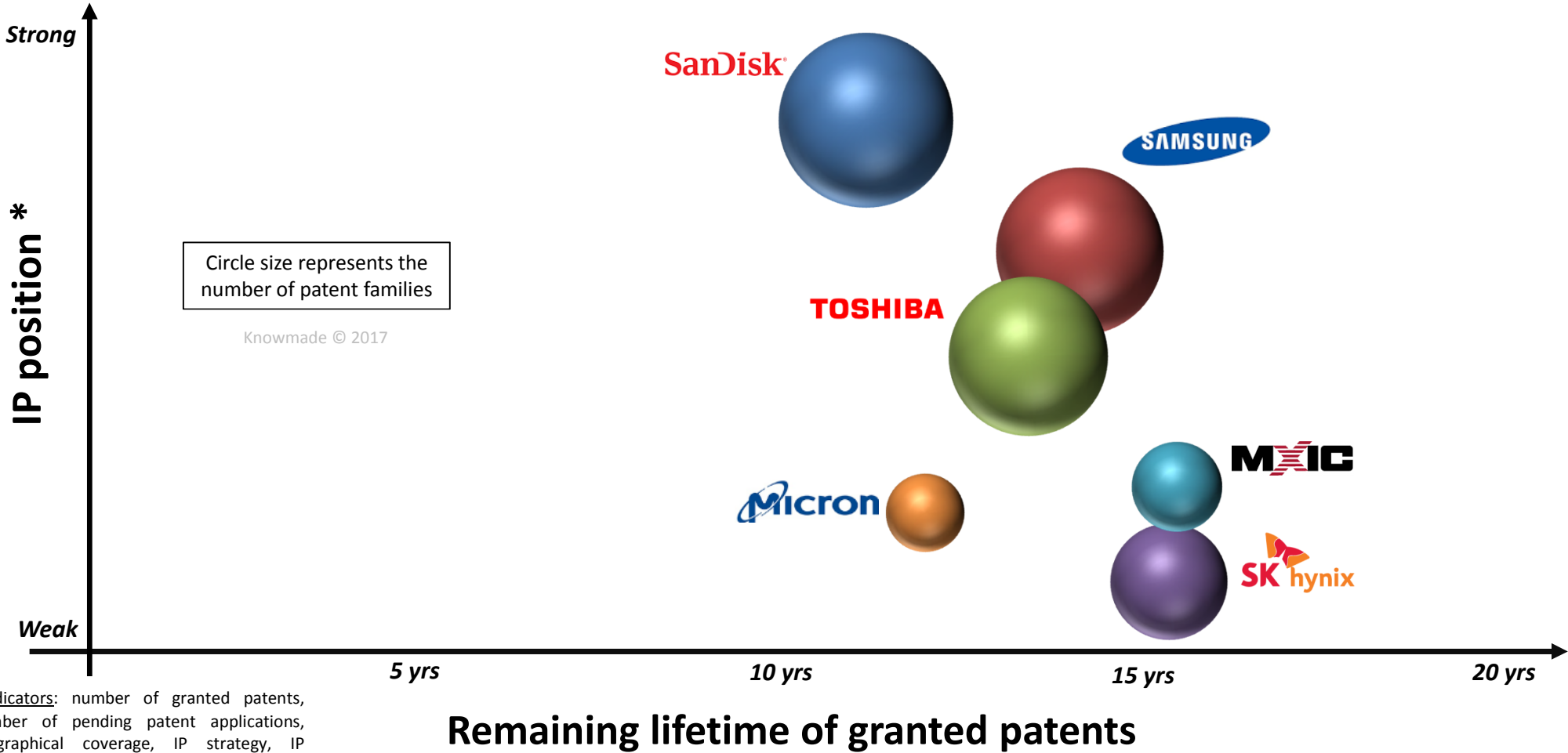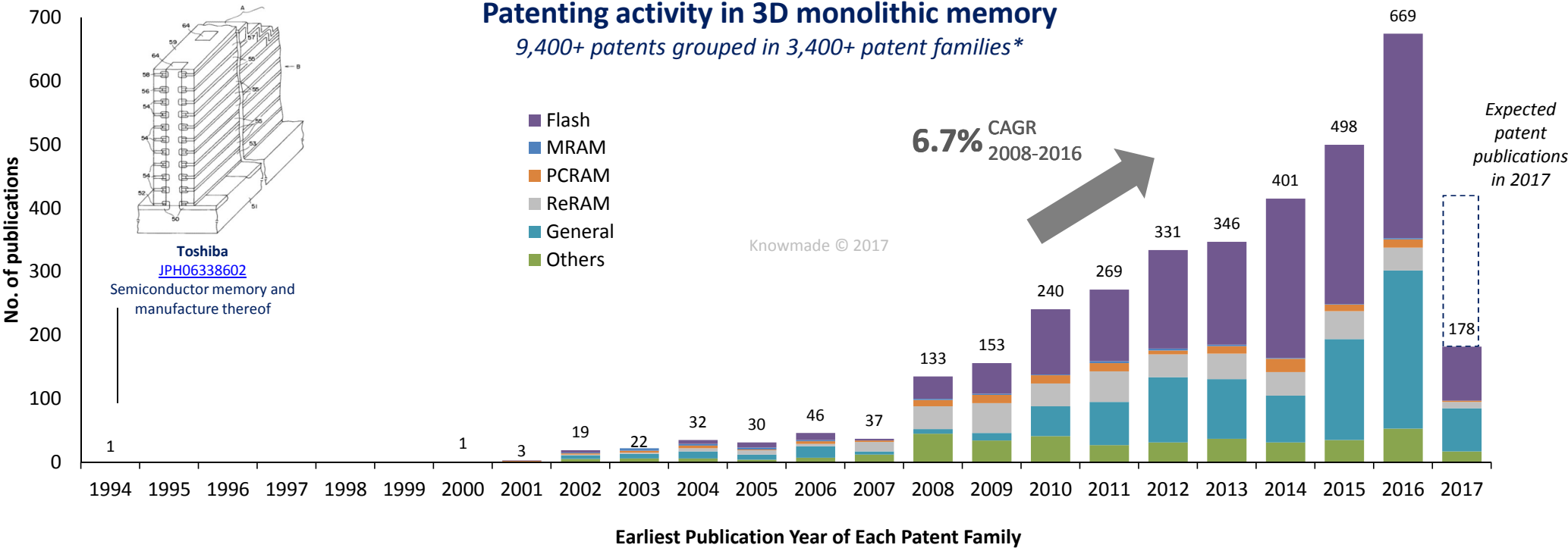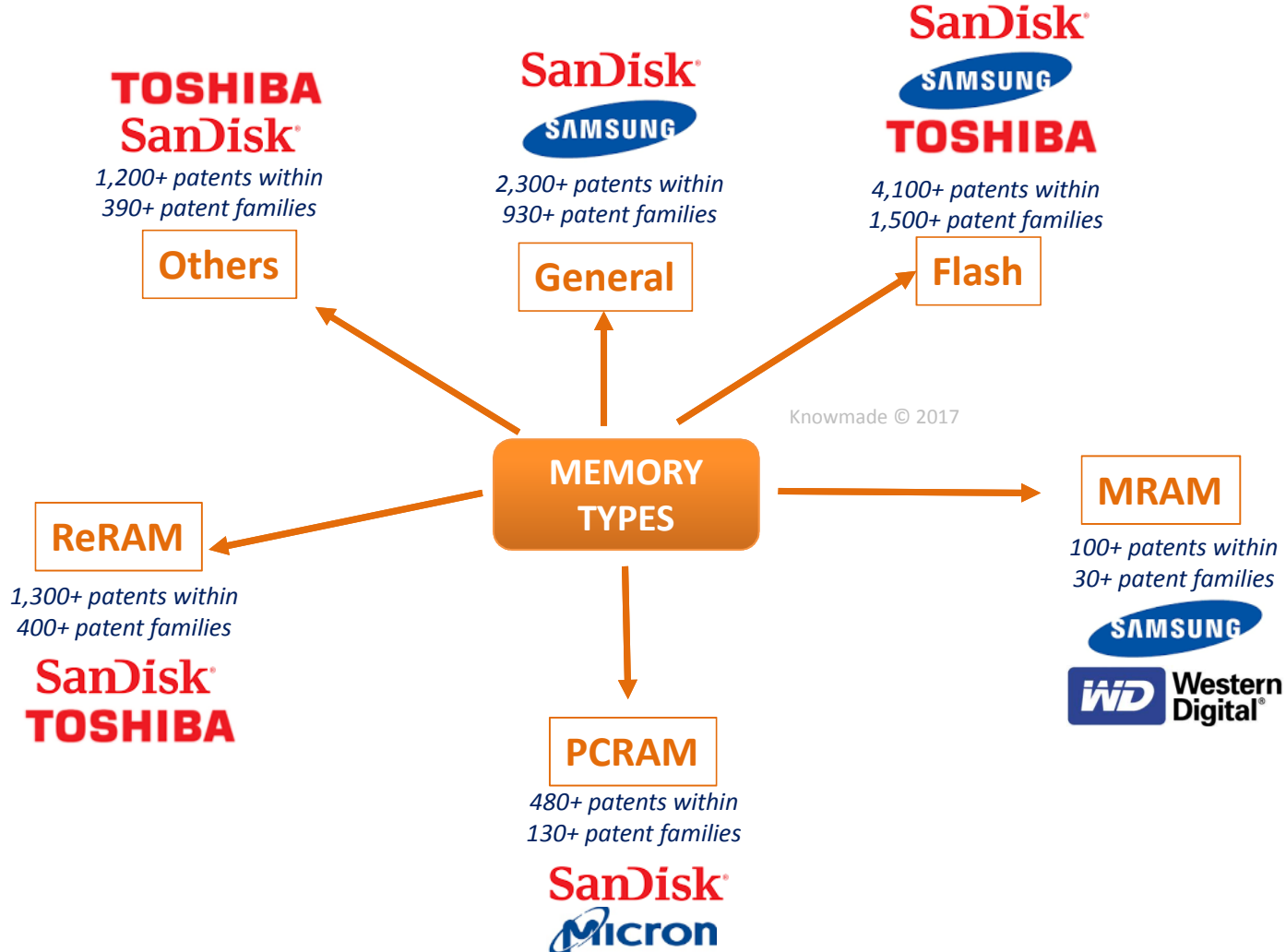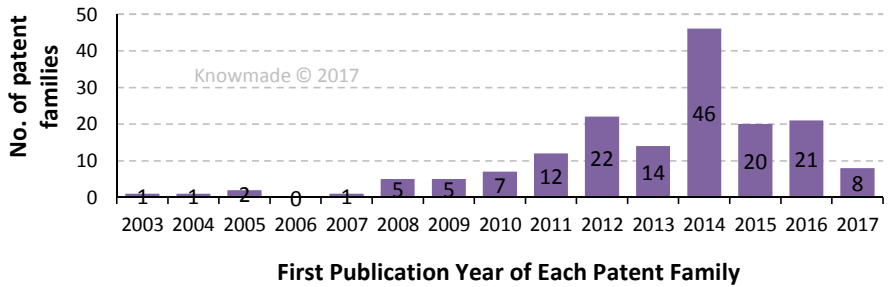
\* A patent family is a set of patents filed in multiple countries to protect a single invention by a common inventor.
A first application is made in one country – the priority country – and is then extended to other countries.

# PATENT SEGMENTATION
## Memory types by key IP players in 3D NVM

**TOSHIBA**
**SanDisk**

*1,200+ patents within 390+ patent families*

**Others**

**SanDisk**
**SAMSUNG**

*2,300+ patents within 930+ patent families*

**General**

**SanDisk**
**SAMSUNG**
**TOSHIBA**

*4,100+ patents within 1,500+ patent families*

**Flash**

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**MEMORY TYPES**

**ReRAM**

*1,300+ patents within 400+ patent families*

**SanDisk**
**TOSHIBA**

**MRAM**

*100+ patents within 30+ patent families*

**SAMSUNG**
**WD Western Digital**

**PCRAM**

*480+ patents within 130+ patent families*

**SanDisk**
**Micron**

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# TECHNOLOGY OVERVIEW
## Micron Technology IP Portfolio in 3D NVM

**722 patents within 165 patent families on 3D NVM**

**First Publication Year of Each Patent Family**

No. of patent families: 2003: 1, 2004: 1, 2005: 2, 2006: 0, 2007: 1, 2008: 5, 2009: 5, 2010: 7, 2011: 12, 2012: 22, 2013: 14, 2014: 46, 2015: 20, 2016: 21, 2017: 8

**Countries of Patent Filings for Patents Related to 3D NVM**

No. of patent families: US: 162, TW: 70, CN: 59, KR: 56, EP: 37, JP: 36

**Alive IP for 3D NVM**

Europe: 14 / 64
Korea: 61 / 44
Japan: 50 / 18
China: 60 / 59
Taiwan: 62 / 18
USA: 263 / 72

● *Number of granted patents*
● *Number of pending patents*

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**Segmentation for Patents Related to 3D NVM**

No. of patent families: FLASH: 86, PCRAM: 25, ReRAM: 17, MRAM: 3, General: 31, Others: 9

• In 2012-2013, Micron was actively working on improving 3D memory architectures as evidenced by the numerous patents published in 2014.
• Half of Micron's patent publications are related to Flash Memories
• Micron doesn't have a worldwide IP strategy in 3D NVM. Indeed, Micron has a very strong IP presence in USA and neglect Europe and Asian countries
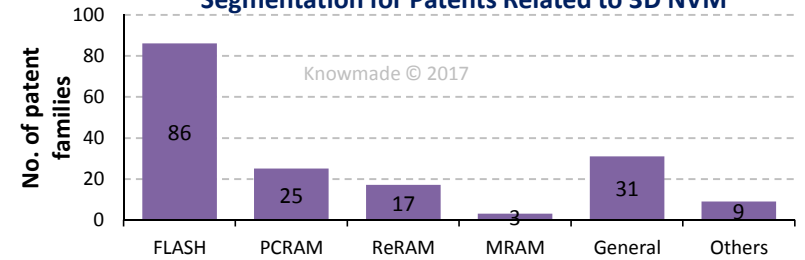
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TSV Stacked Memory

3D NVM

## Conclusion

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# CONCLUSION

- First patents related to 3D memory technologies (TSV Stacked or 3D NVM) were published in the 1990s, but patenting activity really started in the 2000s with a strong increase since 2007-2008 and first marketed products appeared in 2014.

- The patent landscape of 3D memories (TSV Stacked or 3D NVM) is led by the microelectronics giants, offering few space for new entrants and heralding inevitable patent battles.

| Top patent assignees IP position | SanDisk WD Western Digital | | SAMSUNG | | TOSHIBA | | SK hynix | | MXIC | | Micron intel | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TSV Stacked | 3D NVM | TSV Stacked | 3D NVM | TSV Stacked | 3D NVM | TSV Stacked | 3D NVM | TSV Stacked | 3D NVM | TSV Stacked | 3D NVM |
| **IP position** | / | Very Strong | Very Strong | Strong | Very Low | Medium | Low | Very Low | / | Low | Strong | Low |
| **Last and future Products** | / | 3D NAND 64L/512Gb (end 2017) 3D ReRAM In 2019 | HBM2 4Gb and 8Gb in 2016 HBM3 in 2020 | 3D V-NAND Gen4 64L/512Gb (June 2017) "Z-NAND" prototype | 2017/2018 : 1To package of 16 NAND dies TSV stacked, 2To package in 2019 | 3D NAND 64L/512Gb (end 2017) 3D ReRAM In 2019 | Production of HBM2 4Gb and 8Gb in 2016 HBM3 in 2020 | 3D NAND Gen4 72L/256Gb (Q2 2017) 3D NAND 72L/512Gb (end 2017) | / | 3D-NAND product introduction in 2018 | MCDRAM production in 2016 HMC3 in 2020 | 3D NAND Gen2 64L/512Gb (2017) 3D Xpoint Optane Intel/QuantX Micron (2017) |

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