

Alternative Plasma Gas Chemistries for Plasma Enhanced ALD

Plasma-ALD-Guy plasma-ald-guy@plasma-ald.com

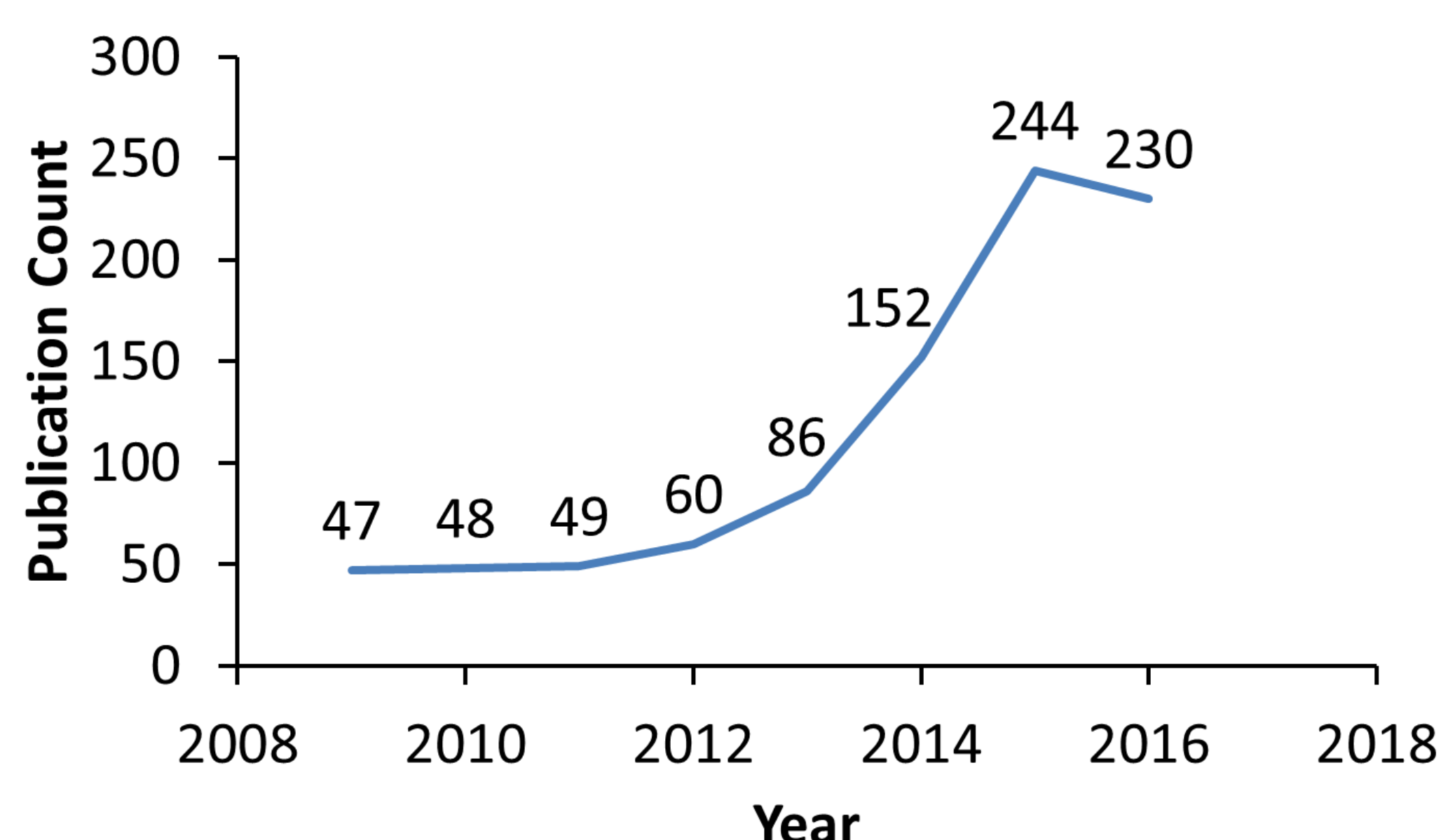
- In Plasma Enhanced ALD (PEALD), thermal ALD molecular co-reactants are replaced with highly reactive plasma generated species offering multiple potential advantages in film selection, film properties, and processing requirements.
- Most PEALD studies utilize a relatively small set of plasma gases including Ar, O₂, N₂, NH₃, and H₂.
- In the table below, less common plasma ALD gases are listed with a brief description of their applications.
- Visit the publication database at plasma-ald.com to learn more about these alternative plasma gas chemistries.

Plasma Gas	Comments
H ₂ O	Yamagata University has demonstrated room temperature deposition of HfO ₂ , ZrO ₂ , and Al ₂ O ₃ with humidified argon plasma
N ₂ O	Al ₂ O ₃ , TiO ₂ , AlTiO _x , HfO ₂ , ZrO ₂ , and ZnO have been deposited with N ₂ O plasma with little to no nitrogen incorporation
CO ₂	Al ₂ O ₃ , TiO ₂ have been deposited with CO ₂ plasma with little to no carbon incorporation
D ₂	Substituting D ₂ plasma has helped elucidate the surface mechanism of Cu deposition from Cu(hfac) ₂ + H ₂ plasma
He	Adding He to the plasma can change plasma density and electron temperature impacting film growth rate and properties
CH ₄	Methane plasma admixing has been studied for introduction of carbon to produce TaCN, TiCN, and WCN
CO	Carbon monoxide plasma has been investigated for introduction of carbon to SiO ₂
PH ₃	GaP has been deposited with trimethyl gallium and phosphine plasma
TMP	Trimethyl phosphate plasma has been studied for Al, Fe, Li, Ti, and Zn phosphate materials
H ₂ S	Hydrogen sulfide plasma has been studied for the deposition of ZnS, MoS ₂ , In ₂ S ₃
CH ₃ NH ₂	SiC _x N _y Using Si ₂ Cl ₆ (R. A. Ovanesyan et al. Chem. Matls. 29(15) 2017.)

2016 Plasma ALD Year in Review

- Plasma-ald.com hosts a freely accessible, highly searchable database of plasma ALD publications currently with 982 entries.
- Plasma ALD publications can be searched by any combination of: film; substrate; precursor and plasma chemistry; deposition hardware; author name and affiliation; film and plasma characteristic, analysis method, and diagnostic equipment; and deposition temperature range.
- After each new year's publications have been entered, a summary review is released to provide an overall picture of the community activities.

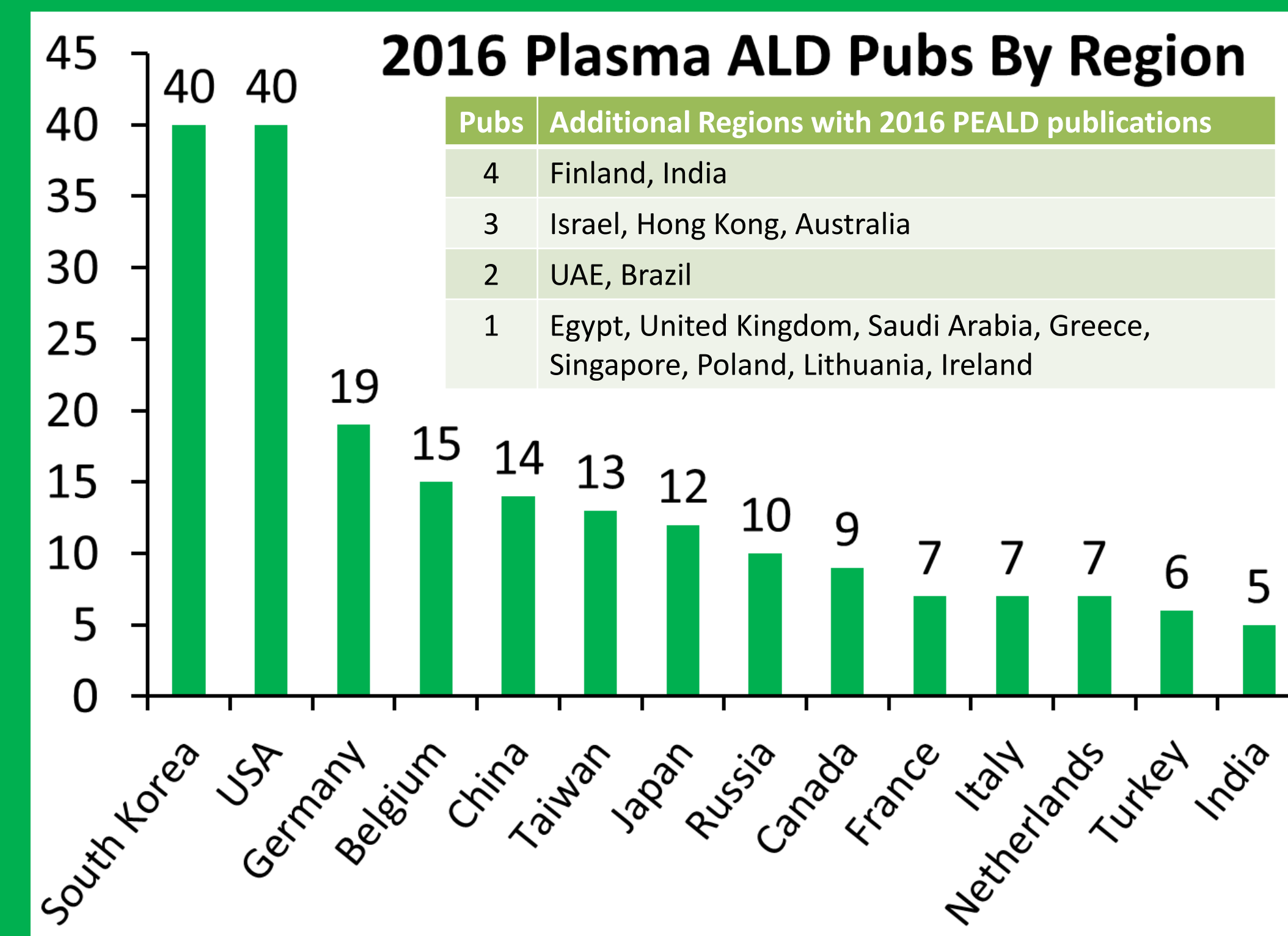
Annual Plasma ALD Publication Count
2009 - 2016



- Strong growth has been seen through 2015 but 2016 did not continue the trend.
- Inclusion in the database has become slightly more selective. Journal publications and conference proceedings are included, but I no longer include conference talks based purely on an abstract.
- The number of ignored conference abstracts not included in this years tally that might have been previously included to number in the 10-20 range. Just enough to make 2016 pretty much in-line with the 2015 numbers. Acceptance date is used for determining the date of a publication.

- As in 2015, South Korea and the USA led the way with Germany in third place.

2016 Plasma ALD Pubs By Region



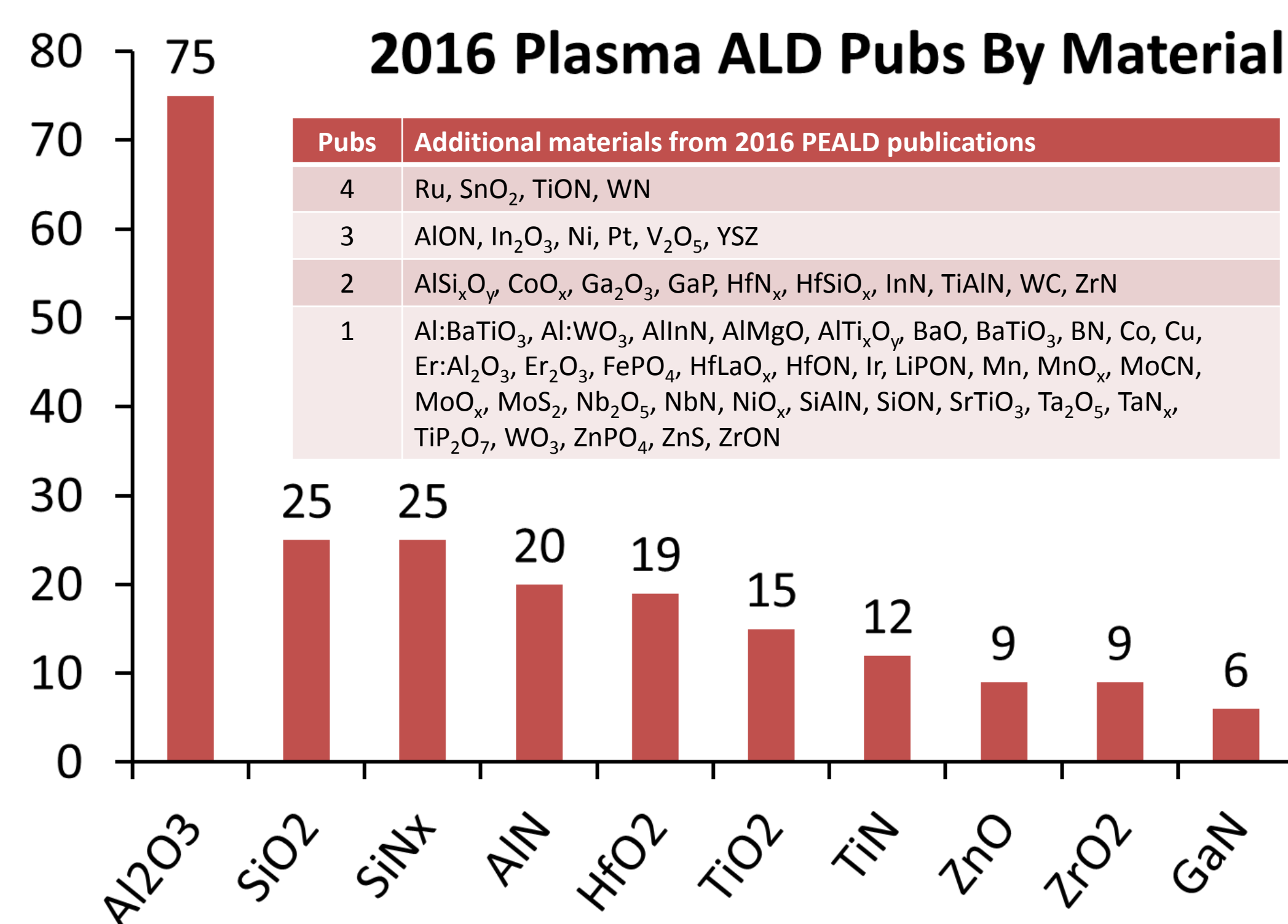
Pubs	Additional Regions with 2016 PEALD publications
4	Finland, India
3	Israel, Hong Kong, Australia
2	UAE, Brazil
1	Egypt, United Kingdom, Saudi Arabia, Greece, Singapore, Poland, Lithuania, Ireland

2009-2016 PEALD Publications
Top 31 PEALD Publication Authors
2009-2016

67	Erwin Kessels
34	Necmi Biyikli
30	Richard van de Sanden
29	Çagla Özgüt-Akgun
27	Hyungjun Kim
20	Christophe Detavernier
19	Ken Cadien, Hyeongtag Jeon, Miin-Jang Chen
17	Harm C. M. Knoop, İnci Dönmez
15	Gijs Dingemans, Kensaku Kanomata
14	Fred Roozeboom
13	Ali Kemal Okyay, Han-Bo-Ram Lee
12	Bashir Ahmmad, Fumihiko Hirose, Sang-Hee Ko Park, Ali Haider, Shigeru Kubota
11	Mustafa Alevli, Soo-Hyun Kim, Douglas W. Barlage
10	Fritz B. Prinz, Jolien Dendooven, J Provine, Hassan Gargouri, Marcel A. Verheijen, Heeyoung Jeon, Jolien Dendooven

The database includes 3061 other authors.

2016 Plasma ALD Pubs By Material



Pubs	Additional materials from 2016 PEALD publications
4	Ru, SnO ₂ , TiON, WN
3	AlON, In ₂ O ₃ , Ni, Pt, V ₂ O ₅ , YSZ
2	AlSiO _x , Co ₃ O ₄ , Ga ₂ O ₃ , GaP, HfN _x , HfSiO _x , InN, TiAlN, WC, ZrN
1	Al:BaTiO ₃ , Al:WO ₃ , AlInN, AlMgO, AlTi ₂ O ₇ , BaO, BaTiO ₃ , BN, Co, Cu, Er:Al ₂ O ₃ , Er ₂ O ₃ , FePO ₄ , HfLaO ₄ , HFON, Ir, LiPON, Mn, MnO ₂ , MoCN, MoO ₃ , MoS ₂ , Nb ₂ O ₅ , NbN, NiO, SiAlN, SiON, SrTiO ₃ , Ta ₂ O ₅ , TaN _x , TiP ₂ O ₇ , WO ₃ , ZnPO ₄ , ZnS, ZrON

- 144 PEALD film materials are listed in the database.
- Al₂O₃ continues to be the most popular material.
- SiO₂ rose from 6th to 2nd.
- SiN_x went from 3rd to tied for 2nd.
- AlN rose from 5th to 4th.
- TiO₂ dropped from 2nd to 6th.
- HfO₂ dropped from 4th to 5th.

Deposition Hardware

- Deposition hardware for 2/3 of the 2016 PEALD films have been identified.
- 13% of the papers utilized custom, homemade hardware.
- 24 different commercial deposition systems were used for the remaining 53% of films including: Aixtron Genus Strategem 200; Altatech AltaCVD; Applied Materials Producer GTTM, P-5000 Mark II, and TxZ chamber; ASM Eagle XP8 and EmerALD; Atomic Premium CN1; Beneq TFS-200 and TFS-500; Cambridge NanoTech Fiji; Ensure LabNano PE; Kemicro PEALD-150; Kurt J. Lesker ALD-150LX; NCD Lucida MP-100; Oxford Instruments FlexAL, OpAL, and Plasmalab 100; Jiaying Kemicro Microelectronic PEALD-200A; Picosun R200 and SUNALE R-150B; Quoros Plus 150 and 200; and SENTECH
- The database includes publications from 23 other deposition systems as well.

Plasma-enhanced atomic layer deposition is an exciting, growing field that is becoming more recognized as an indispensable tool to researchers outside the ALD community. The free, on-line database at www.plasma-ald.com can help you quickly find PEALD publications that will help you with your research interests.

If you have any questions or comments, please send me an email: plasma-ald-guy@plasma-ald.com