



Electronics Materials Information

| 2018-19

Photoresists & Ancillaries

Materials for Semiconductor Manufacturing

A TECHCET Critical Materials Report™

Prepared by

Ed Korczynski

Reviewed and Edited by Lita Shon-Roy

TEHCET CA LLC

PO Box 3814

Rancho Santa Fe, CA 92067

www.TEHCET.com

info@TEHCET.com

[+1-480-382-8336](tel:+14803828336)

Control #

COPYRIGHT 2018 TECHCET CA, All Rights Reserved. COMPANY INTERNAL USE ONLY

Table of Contents

1	Scope, Purpose, & Methodology	8
1.1	Scope	8
1.2	Purpose.....	8
1.3	Methodology	8
1.4	TECHCET 5-Year Wafer Forecast	9
2	Executive Summary	11
2.1	Business Trends	11
2.1.1	Mature market dominated by huge corporations	11
2.1.2	Steady growth in demand for lithography materials	11
2.2	Technology Trends	12
2.2.1	ArFi will remain industry "work-horse"	12
2.2.2	EUV Finally Ready for HVM.....	12
2.3	Market Outlook with 5-Year CAGR.....	15
2.3.1	Visible and DUV Resist Forecast	15
2.3.2	EUV Resist Forecast	15
2.3.3	Extension Materials Forecast.....	16
2.3.4	Ancillaries Forecast	16
2.4	Supply-Chain Dynamics	17
2.5	EHS & Global Logistics Issues	18
2.5.1	US EPA TSCA listing of NMP solvent.....	18
3	Market Segment Outlooks	19
3.1	Overview of global lithography materials market	19
3.1.1	Optical Wavelength & Next Generation Lithography	19
3.1.2	Lithography Materials Defined.....	20
3.2	Technology Factors driving changes in supply and demand.....	21
3.2.1	Lithography Technology Roadmaps	21
3.2.2	Lithography Materials Atomic Scale Interactions	26
3.3	EUV Lithography now in pilot production	30
3.3.1	EUV Resists - CAR & MCR	34
3.3.2	EUV Extensions and Ancillaries	36

3.3.3	Stochastics Limit EUV Resists	38
3.4	Cost Per Wafer Pass (CPWP) modeling of lithography options	43
3.5	5-Year Forecasts of volume demands and market revenues	50
3.5.1	Visible and DUV Resist Forecast	51
3.5.2	EUV Resist Forecast	53
3.5.3	Extension Materials Forecast.....	55
3.5.4	Ancillaries Forecast	56
3.6	Market shares of leading photoresist suppliers	58
3.7	Supplier business models and market dynamics	59
4	Environment, Health, and Safety	61
4.1	Global supply-chains versus local protectionism	61
4.2	REACH and TSCA regulation updates by region	61
4.3	Supply-Chain Disruptions.....	64
5	Supplier Profiles including Business & Technology	65
5.1	Avantor (J.T.Baker).....	65
5.2	Brewer Science / Nissan Chemical	67
5.3	DowDuPont (Rohm & Haas)	71
5.4	Eastman Chemical.....	76
5.5	FujiFilm (Hunt).....	78
5.6	JSR.....	81
5.7	Kempur	83
5.8	KMG	84
5.9	Merck / EMD (AZ)	85
5.10	SACHEM.....	87
5.11	Shin-Etsu.....	88
5.12	Sumitomo / Dongwoo Fine-Chem	89
5.13	Tama Chemical / Moses Lake Industries	93
5.14	Tokyo Ohka Kogyo / Chang Chun	95
6	Appendix A: References, Terms and Acronyms	98
6.1	Appendices and References.....	98
6.2	Terms and Acronyms.....	98

Table of Figures

page #

Figure 1. TECHCET WW silicon semiconductor wafer start forecast.	9
Figure 2. Unit-process steps needed for ArFi-MP versus EUV. (Source: ASML)	13
Figure 3. (LEFT) SEM plan-view of Contact Holes (CH) patterned using EUV, and (RIGHT) plots of CD distributions using either ArFi-MP or EUV. (Source: Intel Corp.).....	14
Figure 4. WW semiconductor fab total market size for photoresists 2014-2023, showing details of resist types sold during 2014-2018.	15
Figure 5. WW semiconductor fab lithography materials market forecast 2014-2023.	18
Figure 6. Industry roadmap for when different patterning technologies would be needed in manufacturing. (Source: IEEE IRDS).....	22
Figure 7. Minimum pitch limits of different patterning technologies. (Source: IMEC)	22
Figure 8. Process-flow needed to accomplish a LELE pattern. (Source: ASML)	23
Figure 9. Self-Aligned Quadruple Patterning (SAQP) traditional process flow yield can be improved using a "fly-cut" series of additional process steps. (Source: TEL).....	24
Figure 10. Different minimum pitches of patterns used by the foundries and by Intel, along with likely lithography technologies deployed. (Source IC Knowledge)	25
Figure 11. Comparing the relatively "attractiveness" of ArFi (193i) or EUV for patterning different device features over time. (Source: GlobalFoundries)	26
Figure 12. Resist stack of materials continues to add layers and complexity, with 5 layers shown here in cross-section for etching deep holes for 3D-NAND. (Source: Macronix).....	28
Figure 13. Chemical Trim Overcoat (CTO) material extends resolution at the same pitch. (Source: DowDuPont).....	29
Figure 14. Resolution and Line-Edge Roughness and Sensitivity (RLS) triangle of trade-offs in photoresists.	29
Figure 15. Status of EUV lithography technology in 2018. (Source: ASML).....	31
Figure 16. Second-generation EUV pellicle technology is based on a felt of carbon nano-tubes (CNT). (Source: IMEC).....	33

Figure 17. Higher exposure dose with EUV resists inherently reduces stochastic defects. (Source: IMEC)	35
Figure 18. EUV CAR developed in either TMAH or TBAH, showing advantages in use of TBAH with an ideal rinse. (Source: SEMATECH)	37
Figure 19. PROLITH simulation of an EUV exposure showing how stochastics in the Latent Image get developed. (Source: Brunner et al., Proc. of SPIE Vol. 10143, 10143E-2)	39
Figure 20. Stochastic failures limit the effective Process Window for EUV lithography. (Source: IMEC)	43
Figure 21. Total CPWP estimates of different patterning options at 22nm pitch.	49
Figure 22. TECHCET forecast of visible and DUV photoresist volume demands 2014-2023....	52
Figure 23. TECHCET forecast of visible and DUV photoresist market size 2014-2023.	53
Figure 24. TECHCET forecast of EUV resist global volume demands 2018-2023.....	54
Figure 25. TECHCET forecast of EUV resist global market size 2018-2023.	55
Figure 26. TECHCET forecast of Extension materials market size 2014-2023.....	56
Figure 27. TECHCET forecast of Ancillary materials market size 2014-2023.....	57
Figure 28. TECHCET forecast of the total world-wide semiconductor lithography materials market size 2014-2023.	58
Figure 29. TECHCET estimate of semiconductor fab photoresist market shares 2017.	59
Figure 30. TSCA enforcement stages. (Source: US EPA).....	62
Figure 31. TSCA best practices for industry. (Source: Keller & Heckman)	62
Figure 32. New Avantor logo. (Source: Avantor).....	66
Figure 33. DSA materials packages. (Source: Brewer Science).....	69
Figure 34. Differences between Graphoepitaxy and Chemoepitaxy process flows for DSA. (Source: Brewer Science)	70
Figure 35. Kempur Microelectronics' product roadmap. (Source: Kempur).....	83
Figure 36. Legacy "AZ" line of lithography materials. (Source: Merck)	86
Figure 37. Sumitomo Chemical investment plan 2016-2021. (Source: Sumitomo).....	90

Figure 38. Sumitomo Chemical ROI by sector in FY2018. (Source: Sumitomo)	91
Figure 39. Sumitomo Chemical exiting underperforming businesses. (Source: Sumitomo)	92
Figure 40. TMAH large package. (Source: Moses Lake Industries)	94
Figure 41. TOK recent financial results compared to mid-term plan targets. (Source: TOK).....	96
Figure 42. TOK investment strategy 2018. (Source: TOK)	97

List of Tables

	page #
Table 1. Next Generation Lithography (NGL) technology options, and details of deployment. (Source: IEEE IRDS).....	20
Table 2. Stochastic variability contributions from different components modeled in a prototypical CAR. (Source: 2018 SPIE-AL)	42
Table 3. Inputs to Cost Per Wafer Pass (CPWP) model of different HVM unit processes.....	47
Table 4. Outputs from CPWP modeling of key unit-processes need to form 22nm pitch patterns in different integrated lithography flows.	48
Table 5. Volume of photoresist assumed to be dispensed per 300mm wafer.	51
Table 6. TECHCET forecast of visible and DUV photoresist volume demands 2014-2023.	51
Table 7. 2018 Q2 Acetic Acid production "turn-arounds" for maintenance in China. (Source ICIS)	64
Table 8. Avantor list of manufacturing sites. (Source: Avantor).....	66
Table 9. Brewer Science list of manufacturing sites. (Source: Brewer Science).....	67
Table 10. Nissan Chemical list of manufacturing sites. (Source: Nissan Chemical).....	68
Table 11. DowDuPont list of manufacturing sites. (Source: DowDuPont).....	73
Table 12. FujiFilm list of manufacturing sites. (Source: FujiFilm).....	79
Table 13. JSR list of manufacturing sites. (Source: JSR)	82
Table 14. SACHEM list of manufacturing sites. (Source: SACHEM).....	87

Table 15. Shin-Etsu Chemical list of manufacturing sites. (Source: Shin-Etsu)	88
Table 16. Sumitomo Chemical list of manufacturing sites. (Source: Sumitomo).....	90
Table 17. Moses Lake Industries list of manufacturing sites. (Source MLI)	94
Table 18. TOK list of manufacturing sites. (Source: TOK)	96