Electron-Beam Lithography with Hydrogen Silsesquioxane (HSQ)

Categories:

1. first papers to show useful EBL exposure of HSQ[1,2]
2. develop conditions[9,27,32,35,39,42,43,45,46]
3. high resolution patterning in HSQ[3,5,8,10,11,12,18,33,39,48]
4. time delay effects[7,23,53]
5. high aspect ratio[8,30]
6. 3D patterning[24,28,52]
7. nanoimprint templates[6,38,54,57,58]
8. bi-layer strategies[4,55,56]

Papers in chronological order of date published:

1) H. Namatsu, Y. Takahashi, K. Yamazali, T.Yamaguchi, M. Nagase, "Three-dimensional siloxane resist for the formation of nano-patterns with minimum linewideth fluctuations, " J. Vac. Sci. Technol., B 16 (1998) 69-76.

2) H. Namatsu, F. Yamaguchi, M. Nagase, K.Yamazali, K. Kurihara, "Nanopatterning of a hydrogen silsesquioxane resist with reduced linewidth fluctuations," Microelectron. Eng. 41/42 (1998) 331-334.

3) B. E. Maile, W. Henscheld, H. Kurz, B. Rienks, R. Polman, P. Kaars, "Sub-10 nm linewidth and overlay performance achieved with a fine-tuned EBPG-5000 TFE electron-beam lithography system," Jpn. J. Appl. Phys. 39 (2000) 6836.

4) F. C. M. J. M. van Delft, J. P, Weterings, A. K. van Langen-Suurling, H. Romijn, "Hydrogen silsesquioxane/novolak bilayer resist for high aspect ratio nanoscale electron-beam lithography" J. Vac. Sci. Technol., B 18 (2000) 3419.

5) L. Mallard, C. Cunge, S. Tedesco, B. Dalzotto, J. Foucher, "HSQ hybrid lithography for 20 nm CMOS device development," Microelectron. Eng. 61/62 (2002) 755-761.

6) D. P. Mancini, K. A. Gehoski, E. Ainley, K. J. Nordquist, D. J. Resnick, T. C. Bailey, S. V. Sreenivasan, J. G. Ekerdt, C. G. Willson, "Hydrogen silsesquioxane for direct electron-beam patterning of step and flash imprint lithography templates," J. Vac. Sci. Technol., B 20 (6) (2002) 2896-2901.

7) F. C. M. M. van Delft, "Delay-time and aging effects on contrast and sensitivity of hydrogen silsesquioxane," J. Vac. Sci. Technol., B 20 (2002) 2932-2936.

8) St. Trellenkamp, J. Moers, A. van der Hart, P. Kordos, H. Luth, "Patterning of 25 nm-wide silicon webs with an aspect ratio of 13," Microelectron. Eng. 67/68 (2003) 376-380.

9) W. Henschel, Y. M. Georgiev, H. Kurz, "Study of a high contrast process for hydrogen silsesquioxane as a negative tone e-beam resist," J. Vac. Sci. Technol., B 21 (2003) 2018-2025.

10) W. Henschel, T. Wahlbrink, Y. M. Georgiev, M. Lemme, T. Mollenhauer, B. Vratzov, A. Fuchs, H. Kurz, "Fabrication of 12 nm electrically variable shallow junction metal-oxide-semiconductor field effect transistors on silicon on insulator substrates," J. Vac. Sci. Technol., B 21 (6) (2003) 2975-2979.

11) J. Kretz, L. Dreeskornfeld, J. Hartwich, W. Rosner, "20 nm electron beam lithography and reactive ion etching for the fabrication of double gate FinFET devices," Microelectron. Eng. 67/68 (2003) 763-768.

12) M. J. Word, I. Adesia, P. R. Berger, "Nanometer-period gratings in hydrogen silsesquioxane fabricated by electron beam lithography," J. Vac. Sci. Technol., B 21 (6) (2003) L12-L15

13) J. Alexander Liddle, Farhad Salmassi, Patrick P. Naulleau, Eric M. Gullikson, "Nanoscale topography control for the fabrication of advanced diffractive optics", J. Vac. Sci. Technol. B 21(6), Nov-Dec 2003

14) D. Lauvernier, J. Vilcot, M. Francois, D. Decoster, "Optimization of HSQ resist e-beam processing technique on GaAs material," Microelectron. Eng. 75 (2) (2004) 177-182.

15) Y. M. Georgiev, W. Henschel, A. Fuchs, H. Kurz, "Surface roughness of hydrogen silsesquioxane as a negative tone electron beam resist," Vacuum 77(2) (2004) 117-123.

16) A. Jamieson, C. G. Willson, Y. Hsu, and A. D. Brodie, "Low-Voltage electron beam lithography resist processes: top surface imaging and hydrogen silisesquioxane bilayer, J. Micrlith., Microfab., Microsyst., Vol. 3 No. 3., July (2004) 442-449.

17) G. Larrieu, E. Dubois, "Reactive ion etching of a 20 nanometers tungsten gate using a SF6/N2 chemistry and hydrogen silsesquioxane hard mask resist," J. Vac. Sci. Technol., B 23 (5) (2005) 2046-2050.

18) I. Baek, J. Yang, W. Cho, C. Ahn, K. Im, S. Lee, "Electron beam lithography patterning of sub-10 nm line using hydrogen silsesquioxane for nanoscale device applications, J. Vac. Sci. Technol., B 23 (6) (2005) 3120-3123.

19) W. Weber, G. Ilicali, J. Kretz, L. Deeskornfeld, W. Roesner, W. Hansch, L. Risch, "Electron beam lithography for nanometer-scale planar double-gate transistors," Microelectron. Eng. 78/79 (2005) 206-211.

20) D. Lauvernier, S. Garidel, C. Legrand, J. Vilcot, “Realization of sub-micron patterns on GaAs using HSQ etching mask,” Microelectron. Eng. 77(3-4) (2005) 210-216.

21) J. Kretz, L. Deeskornfeld, G. Ilicali, T. Lutz, W. Weber, “Comparative study of calixarene and HSQ resist systems for the fabrication of sub-20 nm MOSET device demonstrators,“ Microelectron. Eng. 78/79 (2005) 479-483.

22) F. Fruleux-Cornu, J. Penaud, E. Dubois, M. Francois, M. Muller, “An Optimal High Contrast e-beam Lithography Process for the Patterning of Dense Fin Networks” Materials Science and Engineering C 26 (2006) 893-897.

23) N. Clark, A. Vanderslice, R. Grove III, R. R. Krchnavek, “Time-dependent exposure dose of hydrogen silsesquioxane when used as a negative electron-beam resist,” J. Vac. Sci. Technol., B 24 (6) (2006) 3073-3076.

24) E. J. Boyd, R. J. Blaikie, “Three dimensional HSQ structures formed using multiple low energy electron beam lithography,” Microelectron. Eng. 83 (4-9) (2006) 767-770.

25) F. Fruleux-Cornu, J. Penaud, E. Dubois, M. Francois, M. Muller, “Optimization of HSQ e-beam lithography for the patterning of FinFET transistors” Microelectron. Eng. 83 (4-9) (2006) 776-779.

26) H. Yang, A. Jin, Q. Luo, C. Gu, Z. Cui, Y. Chen, “Low-energy electron-beam lithography of hydrogen silsesquioxane,” Microelectron. Eng. 83 (4-9) (2006) 788-791.

27) Y. Chen, H. Yang, Z. Cui, “Effects of developing conditions on the contrast and sensitivity of hydrogen silsesquioxane,” Microelectron. Eng. 83 (4-9) (2006) 1119-1123.

28) Y. Matsubara, J. Taniguchi, I. Miyamoto, “Fabrication of three-dimensional hydrogen silsesquioxane resist structures using electron beam lithography,” Jap. J. Appl. Physics, Part 1, 45(6B) (2006), 5538-5541.

29) Marshal A. Miller, Wojtek J. Poppe, Andrew R. Neureuther, Alex Liddle, Bruce Harteneck, “Pattern noise in electron beam resists: PMMA, KRS-XE, TOK, HSQ” J. Vac. Sci. Technol. B 24 (6), Nov/Dec 2006

30) T. Wahlbrink, Daniel Ku¨pper, Y.M. Georgiev, J. Bolten, M. Moller, David Kupper, M.C. Lemme, H. Kurz, “Supercritical drying process for high aspect-ratio HSQ nano-structures”, Microelectronic Engineering 83 (2006) 1124–1127

31) A. E. Grigorescu, M. C. van der Krogt, C. W. Hagen, “Limiting factors for electron beam lithography when using ultra-thin hydrogen silsesquioxane layers,” J. Micro/Nanolithography, MEMS, and MOEMS, 6(4), (2007) 1-7.

32) A. E. Grigorescu, M. C. van der Krogt, C. W. Hagen, P. Kruit, "Influence of the development process on ultimate resolution electron beam lithography, using ultrathin hydrogen silsesquioxane resist layers," J. Vac. Sci. Technol. B Volume 25, Issue 6 (2007) 1998-2003..

33) A. E. Grigorescu, M. C. van der Krogt, C. W. Hagen, P. Kruit, "10 nm lines and spaces written in HSQ, using electron beam lithography," Microelectron. Eng. 84(5-8) (2007) 822-824.

34) M. Haffner, A. Haug, A. Heeren, M. Fleischer, "Influence of temperature on HSQ electron-beam lithography," J. Vac. Sci. Technol. B Volume 25, Issue 6 (2007) 2045-2048.

35) S. Choi, N. Jin, V. Kumar, I. Adesida, M. Shannon, "Effects of developer temperature on electron-beam hydrogen silsesquioxane resist for ultradense silicon nanowire fabrication," J. Vac. Sci. Technol. B Volume 25, Issue 6 (2007) 2085-2088.

36) T. Lutz, M. Specht, L. Risch, C. Friederich, L. Dreeskornfeld, J. Kretz, W. Weber, W. Roesner, "Fabrication of a nano-scale NAND memory array based on a SONOS Fin-FET cell using e-beam lithography and hydrogen-silsesquioxane resist," Microelectron. Eng., 84(5-8), (2007) 1578-1580.

37) C. M. Hessel, M. A. Summers, A. Meldrum, M. Malac, J. G. C. Veinot, "Direct Patterning, Conformal Coating, and Erbium Doping of Luminescent nc-Si/SiO2 Thin Films from Solution Processable Hydrogen Silsesquioxane," Adv. Mater. 19, (2007) 3513-3516.

38) Ming-Tse Dai, Kai-Yuen Lam, Henry J. H. Chen, Fon-Shan Huang, "Nanocontact Printing Using a Hydrogen Silsesquioxane Stamp with Low E-beam Dose", Journal of The Electrochemical Society, 154 (7) H636-H641 (2007)

39) Joel K. W. Yang, Karl K. Berggren, " Using high-contrast salty development of hydrogen silsesquioxane for sub-10-nm half-pitch lithography", J. Vac. Sci. Technol. B 25 (6) Nov/Dec 2007

40) V. Sidorkin, E. van der Drift, H. Salemink, "Influence of hydrogen silsesquioxane resist exposure temperature on ultrahigh resolution electron beam lithography," J. Vac. Sci. Technol. B Volume 26, Issue 6 (2008) 1071-1023.

41) S. Choi, M. J. Word, V. Kumar, I. Adesida, "Comparative study of thermally cured and electron-beam-exposed hydrogen silsesquioxane resists," J. Vac. Sci. Technol. B Volume 26, Issue 5 (2008) 1654-1659.

42) Sung-Wook Nam, Michael J. Rooks, Joel K. W. Yang, Karl K. Berggren, Hyun-Mi Kim, Min-Hyun Lee, Ki-Bum Kima, Jae Hwan Sim, Do Yeung Yoon, "Contrast

enhancement behavior of hydrogen silsesquioxane in a salty developer", J. Vac. Sci. Technol. B 27 (6) Nov/Dec 2009

43) Jihoon Kim; Weilun Chao; Griedel, B.; Xiaogan Liang; Lewis, M.; Hilken, D.; Olynick, D., "Understanding the base development mechanism of hydrogen silsesquioxane", Source: Journal of Vacuum Science & Technology B (Microelectronics and Nanometer Structures), v 27, n 6, p 2628-34, Nov. 2009

44) Piotr Jedrasik, Dai Tsunoda, Masahiro Shoji, Hiroyuki Tsunoe, "Proximity effects correction for sub-10nm patterning node", Proc. of SPIE Vol. 7638 76383B-2, 2010

45) Katherine J. Harry, Sebastian Strobel, Joel K. W. Yang, Huigao Duan, Karl K. Berggren, "In situ study of hydrogen silsesquioxane dissolution rate in salty and electrochemical developers", J. Vac. Sci. Technol. B 29(6), Nov/Dec 2011

46) Strobel, S.; Harry, K.J.; Huigao Duan; Yang, J.K.W.; Manfrinato, V.R.; Berggren, K.K. "Electrochemical development of hydrogen silsesquioxane by applying an electrical potential", Nanotechnology, v 22, n 37, p 375301 (7 pp.), 16 Sept. 2011

47) Richard J. Bojko, Jing Li, Li He, Tom Baehr-Jones, Michael Hochberg, Yukinori Aida, "Electron beam lithography writing strategies for low loss, high confinement silicon optical waveguides", J. Vac. Sci. Technol. B 29(6), Nov/Dec 2011

48) Vitor R. Manfrinato, Lin Lee Cheong, Huigao Duan, Donald Winston, Henry I. Smith, Karl K. Berggren, "Sub-5 keV electron-beam lithography in hydrogen silsesquioxane resist", Microelectronic Engineering 88 (2011) 3070–3074

49) Vitaliy A. Guzenko, Jörg Ziegler, Anastasia Savouchkina, Celestino Padeste, Christian David, "Fabrication of large scale arrays of metallic nanodots by means of high resolution e-beam lithography", Microelectronic Engineering 88 (2011) 1972–1974.

50) M.A. Mohammad, S.K. Dewa, S. Evoy, M. Stepanova, "Fabrication of sub-10 nm silicon carbon nitride resonators using a hydrogen silsesquioxane mask patterned by electron beam lithography", Microelectronic Engineering 88 (2011) 2338–2341

51) Julia Reinspach, Fredrik Uhlen, Hans M. Hertz, Anders Holmberg, " Twelve nanometer half-pitch W–Cr–HSQ trilayer process for soft x-ray tungsten zone plates", J. Vac. Sci. Technol. B 29(6), Nov/Dec 2011.

52) Vila-Comamala, J.; Gorelick, S.; Guzenko, V.A.; David, C., "3D Nanostructuring of hydrogen silsesquioxane resist by 100 keV electron beam lithography", Journal of Vacuum Science & Technology B (Microelectronics and Nanometer Structures), v 29, n 6, p 06F301 (5 pp.), Nov. 2011

53) Westly, D.A.; Tennant, D.M.; Aida, Y.; Ohki, H.; Ohkubo, T., "Improved time dependent performance of hydrogen silsesquioxane resist using a spin on top coat", Journal of Vacuum Science & Technology B (Microelectronics and Nanometer Structures), v 29, n 6, p 06FJ02 (7 pp.), Nov. 2011

54) Takeru Okada, Jiro Fujimori, Tetsuya Iida, "Nanoimprint Molds with Circumferentially Aligned Patterns Fabricated by Liftoff Process", Japanese Journal of Applied Physics 50 (2011) 126502

55) Wei-Su Chen, Peng-Sheng Chen, Hung-Wen Wei, Frederick T. Chen, Ming-Jinn Tsai, Tzu-Kun Ku, " Substrate and Underlayer Dependence of Sub-32 nm E-beam HSQ Pillar Patterning Process for RRAM Application", Proc. of SPIE Vol. 8325, 83250V, (2012)

56) Wei-Su Chen, Peng-Sheng Chen, Hung-Wen Wei, Frederick T. Chen, Ming-Jinn Tsai, Tzu-Kun Ku," Transfer Optimized Dry Development Process of Sub-32 nm HSQ/AR3 BLR Resist Pillar from Low-K Etcher to Metal Etcher", Proc. of SPIE Vol. 8328, 83280P, (2012)

57) Muhammad Rizwan Saleem, Petri Antero Stenberg, Muhammad Bilal Khan, Zaffar Muhammad Khan, Seppo Honkanen, Jari Turunen, "Hydrogen silsesquioxane resist stamp for replication of nanophotonic components in polymers", J. Micro/Nanolith. MEMS MOEMS 11(1), 013007 (Jan–Mar 2012)

58) M. R. Saleem , P. A. Stenberg , M. B. Khan , Z. M. Khan , S. Honkanen , J. Turunen, "HSQ resist for replication stamp in polymers", Proc. of SPIE Vol. 8249 82490G-1, (2012)

59) Shah, F.A.; Kyoung Nan Kim; Lieberman, M.; Bernstein, G.H., "Roughness optimization of electron-beam exposed hydrogen silsesquioxane for immobilization of DNA origami", Journal of Vacuum Science & Technology B (Microelectronics and Nanometer Structures), v 30, n 1, p 011806 (6 pp.), Jan. 2012