Modelling and optimization of the technology process by ion beam etching

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The study tested the problem of optimal control of ion beam etching to minimize geometric dimensions of the etched elements. This problem is solved by changing the angle of incidence of the ion beam in relation to the target (IBE method). Advanced techniques for creating embossing functional layers, including various ways of dry etching, are necessary for making chips with submicron elements. One of those ways is the ion-beam etching (IBE) based on the action of mono electric ion beams. It permits to change the angle of the target in relation to the ion beam, thereby to control the angle of the etched elements. One of the advantages of IBE is the availability of sufficiently accurate mathematical model. Evolution of the freeform surface during ion beam etching is described by the essentially nonlinear hyperbolic equation of the first order. The paper describes the function that determines the angle formed by the beam of the incidence of the ions to the sputtered surface, for two-dimensional and three-dimensional cases. To characterize the degree of drifting geometrical dimensions, we introduced the functional and set the problem of optimal control with non-fixed time. However, due to the special features of the IBE process, we succeeded in bringing the time-fixed problem to the fixed-time one. For this problem, using the technique of singular variations, we established Pontryagin maximum principle. Based on this principle, we designed software package to search for the optimal regimes for different initial profiles. It should be noted, that to search for the optimal control, it is not necessary to solve the adjoint system, which greatly facilitates the computational process. We also examined the IBE process for the semicircular initial mask. For comparison, we performed calculations with the optimal control and without it and made appropriate conclusions.

Keywords: *IBE methods, optimal control, L.S. Pontryagin principle maximum.*

REFERENCES

[1] Dutton R. W., Hansen S. E. Process Modeling of Integrated Circuit Device Technology. *Proceedings of the IEEE*, 2001, vol. 69, no 10, pp. 1305–1320.

[2] Ryssel H., Habberg K., Hoffmann K., Prinke G., Dumcke R., Sachs A. Simulation of Doping Processes. *IEEE Trans on electron devices*, 2000, vol. 27, no. 8, pp. 1484–1492.

[3] Gushin M. B., Ivanov R. D., Labutin E. S. etc. Model Profile Evolution Photo Resistive Protective Mask During Ion Beam Etching. *Electronic Technician. Ser. 3. Microelectronics*, 1979, no. 2, p. 90.

[4] Docommuh I. D., Gantagrel M., Moulin M. Evolution of Well-Divined Surface Contour Submitted to Ion Bombardment. *J. of Materials Sci. Left*, 1981, no. 10, p. 52.

[5] Muravey L. A., Petrov V. M. Optimal Control of Technological Processes in Microelectronics. *Interpribor-90*, Moscow, 1990, pp. 51–53.

[6] Muravey L. A., Petrov V. M. Simulation and Optimization Problems of Some Technological Processes in Microelectronics. *SIAM Conference on Mathematics Industry*, San Francisco, USA, 2009, p. 26.
[7] Muravey L. A., Petrov V. M. Coefficient Control for Some Nonlinear Hyperbolic Equation. *1062nd AMS MEETING, Syracuse University*. Syracuse, New York, 2010, p. 34–35.
[8] Muravey L. A., Petrov V. M., Romanenkov A. M. Modeling and Optimization of Ion-Beam Etching Process. *Proceedings. III International conference on optimization methods and applications (OPTIMA-2012)*. Costa da Caparica, 2012.
[9] Gurchenkov A.A., Eleonsky V.M., Kulagin N.E. *O sopostavlenii bifurkatsii v klassicheskoi i kvantovoi mekhanike. Sluchai integriruemykh sistem* [On comparing the bifurcations in classical and quantum mechanics. The case of integrable systems]. Moscow, 2009, CC RAS Publ., 84 p.
[10] Gurchenkov A.A., Esenkov A.S., Tsurkov V.I. *Izvestiya RAN. Teoriya i sistemy upravleniya — Proceedings of the Russian Academy of Sciences. Control theory and systems*, 2006, no. 3, pp. 82–89.
[11] Gurchenkov A.A., Esenkov A.S., Tsurkov V.I. *Izvestiya RAN. Teoriya i sistemy upravleniya — Proceedings of the Russian Academy of Sciences. Control theory and systems*, 2006, no. 1, pp. 141–148.
[12] Gurchenkov A.A. *Izvestiya vuzov. Ser. Priborostroenie — University Proced. Ser. Instrument engineering*, 2001, vol. 44, no. 2, p. 44.
[13] Gurchenkov A.A. *Inzhenerno-fizicheskiy zhurnal — Journal of Engineering Physics*, 2002, vol. 75, no. 3, pp. 28–32.
[14] Gurchenkov A.A., Yalamov Y.I. *Doklady Physics*, 2002, vol. 47. no. 1, pp. 25—28.
[15] Gurchenkov A.A. *Prikladnaya mekhanika i tekhnicheskaya fizika — Applied Mechanics and Technical Physics*, 2001, vol. 42, no. 4, pp. 48–51.
[16] Gurchenkov A.A., Korneev V.V., Nosov M.V. *Prikladnaya matematika i mekhanika — Applied Mathematics and Mechanics*, 2008, vol. 72, no. 6, pp. 904–911.
[17] Gurchenkov A.A. *Dokl. Akademii nauk — Acad. Sci. reports*, 2002, vol. 382, no. 4, p. 476.
[18] Gurchenkov A.A., Nosov M.V, Tsurkov V.I. *Control of Fluid-Containing Rotating Rigid Bodies*. CRS Press, 2013, 147 p. (in English).
[19] Gurchenkov A.A. *Prikladnaya matematika i mekhanika — Applied Mathematics and Mechanics*, 2002, vol. 66, iss. 2, pp. 251–255.
[20] Gurchenkov A.A., Eleonskii V.M., Kulagin N.E. *Sloistye struktury v nelineinykh vektornykh poliakh* [Layered structures in nonlinear vector fields]. Moscow, Comp. Center RAS Publ., 2007, 177 p.
[21] Gurchenkov A.A., Kulagin N.E. *Ob uzorakh simmetrii v prostykh modeliakh nelineinogo skaliarnogo polia* [Patterns of symmetry in simple models of nonlinear scalar field]. Moscow, Comp. Center RAS, 2004, 84 p.
[22] Gurchenkov A.A., Moroz I.I., Popov N.N. *Inzhenernyi zhurnal: nauka i innovatsii — Engineering Journal: Science and Innovation*, 2013, iss. 9. Available at: http://engjournal.ru/catalog/appmath/hidden/1166.html
[23] Gurchenkov A.A., Romanenkov A.M. *Inzhenernyi zhurnal: nauka i innovatsii — Engineering Journal: Science and Innovation*, 2013, iss. 2. Available at: http://engjournal.ru/catalog/appmath/hidden/613.html
[24] *Gurchenkov A.A. Inzhenernyi zhurnal: nauka i innovatsii — Engineering Journal: Science and Innovation*, 2013, iss. 2. Available at: http://engjournal.ru/catalog/appmath/hidden/603.html

[25] Gurchenkov A.A. *Vestnik MGTU im. N.E. Baumana. Ser. Estestvennye nauki — BMSTU Bulletin. Ser. Natural Sciences*, 2012, spec. iss. no. 7, pp. 18–31.
[26] Gurchenkov A.A. *Dinamika zavikhrennoi zhidkosti v polosti vrashchayushchegosya tela* [Dynamics of swirling liquid in the cavity of the rotating body]. Moscow, Fizmatlit Publ., 2010, 221 p.
[27] Gurchenkov A.A., Nosov M.V., Tsurkov V.I. *Upravlenie vrashchayushchimisya tverdymi telami s zhidkostyu* [Control of rotating solids with the fluid]. Moscow, Fizmatlit Publ., 2011, 202 p.

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