



(12) **United States Patent**  
**Chistyakov**

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(54) **PLASMA GENERATION USING MULTI-STEP IONIZATION**

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(52) **U.S. Cl.** ..... **204/298.36**; 204/298.37; 204/298.38; 118/723 VE; 118/723 R; 315/111.81; 315/111.91

(58) **Field of Search** ..... 315/111.81, 111.91, 315/111.71, 111.41, 111.21; 204/298.37, 298.38, 298.36; 118/723 VE, 723 R, 723 EB, 723 E; 250/28, 283, 377, 423, 435, 489

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

3,619,605 A	11/1971	Cook et al. ....	250/41.9
4,060,708 A	11/1977	Walters .....	219/121
4,148,612 A	4/1979	Taylor et al. ....	23/232
4,546,253 A	10/1985	Tsuchiya et al. ....	250/288
4,703,222 A	10/1987	Yoshikawa et al. ....	313/362.1
4,792,725 A	12/1988	Levy et al. ....	315/39
4,802,183 A	1/1989	Harris et al. ....	372/57
4,919,690 A	4/1990	Lovelock .....	55/2
4,953,174 A	8/1990	Eldridge et al. ....	372/87
5,015,493 A	5/1991	Gruen .....	427/38
5,083,061 A	1/1992	Koshiishi et al. ....	315/111.81
5,247,531 A	9/1993	Muller-Horsche .....	372/38
5,247,535 A	9/1993	Muller-Horsche et al. ....	372/86
5,286,360 A	2/1994	Szczyrbowski et al. ....	204/298.08

5,382,457 A	1/1995	Coombe .....	427/596
5,506,405 A	4/1996	Yoshida et al. ....	250/251
5,733,418 A	3/1998	Herscovitch et al. .	204/192.11
5,821,548 A	10/1998	Hinchliffe .....	250/492.21
6,057,244 A	5/2000	Hausmann et al. ....	438/706

(List continued on next page.)

**FOREIGN PATENT DOCUMENTS**

WO	WO 98/40532	9/1998
WO	WO 01/98553 A1	12/2001

**OTHER PUBLICATIONS**

Booth, et al., The Transition From Symmetric To Asymmetric Discharges In Pulsed 13.56 MHz Capacitively Coupled Plasmas, J. Appl. Phys., Jul. 15, 1997, pp. 552-560, vol. 82, No. 2, American Institute of Physics.

Bunshah, et al., Deposition Technologies For Films And Coatings, pp. 178-183, Noyes Publications, Park Ridge, New Jersey.

Daugherty, et al., Attachment-Dominated Electron-Beam-Ionized Discharges, Applied Physics Letters, May 15, 1976, pp. 581-583, vol. 28, No. 10, American Institute of Physics.

(List continued on next page.)

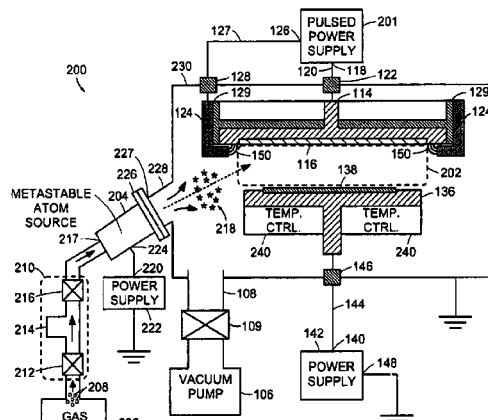
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(57) **ABSTRACT**

The present invention relates to a plasma generator that generates a plasma with a multi-step ionization process. The plasma generator includes an excited atom source that generates excited atoms from ground state atoms supplied by a feed gas source. A plasma chamber confines a volume of excited atoms generated by the excited atom source. An energy source is coupled to the volume of excited atoms confined by the plasma chamber. The energy source raises an energy of excited atoms in the volume of excited atoms so that at least a portion of the excited atoms in the volume of excited atoms is ionized, thereby generating a plasma with a multi-step ionization process.

**46 Claims, 13 Drawing Sheets-**



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## U.S. PATENT DOCUMENTS

6,124,675	A	9/2000	Bertrand et al. ....	315/111.91
6,207,951	B1	3/2001	Yamauchi et al. ....	250/251
6,296,742	B1	10/2001	Kouznetsov .....	204/192.12
6,311,638	B1	* 11/2001	Ishii et al. ....	118/723 MW
6,395,641	B2	5/2002	Savas .....	438/714
6,413,382	B1	7/2002	Wang et al. ....	204/192.12
6,413,383	B1	7/2002	Chiang et al. ....	204/192.13
6,661,178	B1	* 12/2003	Bertrand et al. ....	315/111.91
2002/0153103	A1	10/2002	Madocks .....	156/345.46

## OTHER PUBLICATIONS

Goto, et al., Dual Excitation Reactive Ion Etcher For Low Energy Plasma Processing, *J. Vac. Sci. Technol. A*, Sep/Oct 1992, pp. 3048–3054, vol. 10, No. 5, American Vacuum Society.

Kouznetsov, et al., A Novel Pulsed Magnetron Sputter Technique Utilizing Very High Target Power Densities, *Surface and Coatings Technology*, 1999, pp. 290–293, vol. 122, Elsevier Science S.A.

Lindquist, et al., High Selectivity Plasma Etching Of Silicone Dioxide With A Dual Frequency 27/2 MHz Capacitive RF Discharge.

Macak, Reactive Sputter Deposition Process Of Al<sub>2</sub>O<sub>3</sub> And Characterization Of A Novel High Plasma Density Pulsed Magnetron Discharge, *Linkoping Studies In Science And Technology*, pp. 1–2.

Macak, et al., Ionized Sputter Deposition Using An Extremely High Plasma Density Pulsed Magnetron Discharge, *J. Vac. Sci. Technol. A*, Jul/Aug 2000, pp. 1533–1537, vol. 18, No. 4, American Vacuum Society.

Mozgrin, et al., High-Current Low-Pressure Quasi-Stationary Discharge In A Magnetic Field: Experimental Research, *Plasma Physics Reports*, 1995, pp. 400–409, vol. 21, No. 5.

Rosnagel, et al., Induced Drift Currents In Circular Planar Magnetrons, *J. Vac. Sci. Technol. A*, Jan/Feb 1987, pp. 88–91, vol. 5, No. 1, American Vacuum Society.

Sheridan, et al., Electron Velocity Distribution Functions In A Sputtering Magnetron Discharge For The E × B Direction, *J. Vac. Sci. Technol. A*, Jul/Aug 1998, pp. 2173–2176, vol. 16, No. 4, American Vacuum Society.

Steinbruchel, A Simple Formula For Low-Energy Sputtering Yields, *Appl. Phys. A*, 1985, pp. 37–42, vol. 36, Sprigener Verlag.

*Encyclopedia Of Low Temperature Plasma*, p. 119, vol. 3.

*Encyclopedia Of Low Temperature Plasma*, p. 123, vol. 3.

Lymberopoulos, et al., Fluid Simulations Of Glow Discharges: Effect Of Metastable Atoms In Argon, *J. Appl. Phys.*, Apr. 1993, pp. 3668–3679, vol. 73, No. 8, American Institute of Physics.

Burnham, et al., Efficient Electric Discharge Lasers In XeF and KrF, *Applied Physics Letters*, Jul. 1976, pp. 30–32, vol. 29, No. 1, American Institute of Physics.

Fabrikant, et al., Electron Impact Formation Of Metastable Atoms, pp. 3, 31, 34–37, Amsterdam.

Fahey, et al., High Flux Beam Source Of Thermal Rare-Gas Metastable Atoms, 1980, *J. Phys. E. Sci. Instrum.*, vol. 13, The Institute of Physics.

Verheijen, et al., A Discharge Excited Supersonic Source Of Metastable Rare Gas Atoms, *J. Phys. E. Sci. Instrum*, 1984, vol. 17.

Eletskii, Excimer Lasers, *Sov. Phys. Usp.*, Jun. 1978, pp. 502–521, vol. 21, No. 6.

Chistyakov, High Power Pulsed Magnetron Sputtering, Application No.: 10/065, 277, Filed: Sep. 30, 2002.

Chistyakov, High-Power Pulsed Magnetically Enhanced Plasma Processing, Application No.: 10/065, 551, Filed: Oct. 29, 2002.

Chistyakov, Method and Apparatus For Generating High-Density Plasma, Application No.: 10/065, 629, Filed: Nov. 4, 2002.

Chistyakov, High Deposition Rate Sputtering, Application No.: 10/065, 739, Filed: Nov. 14, 2002.

\* cited by examiner

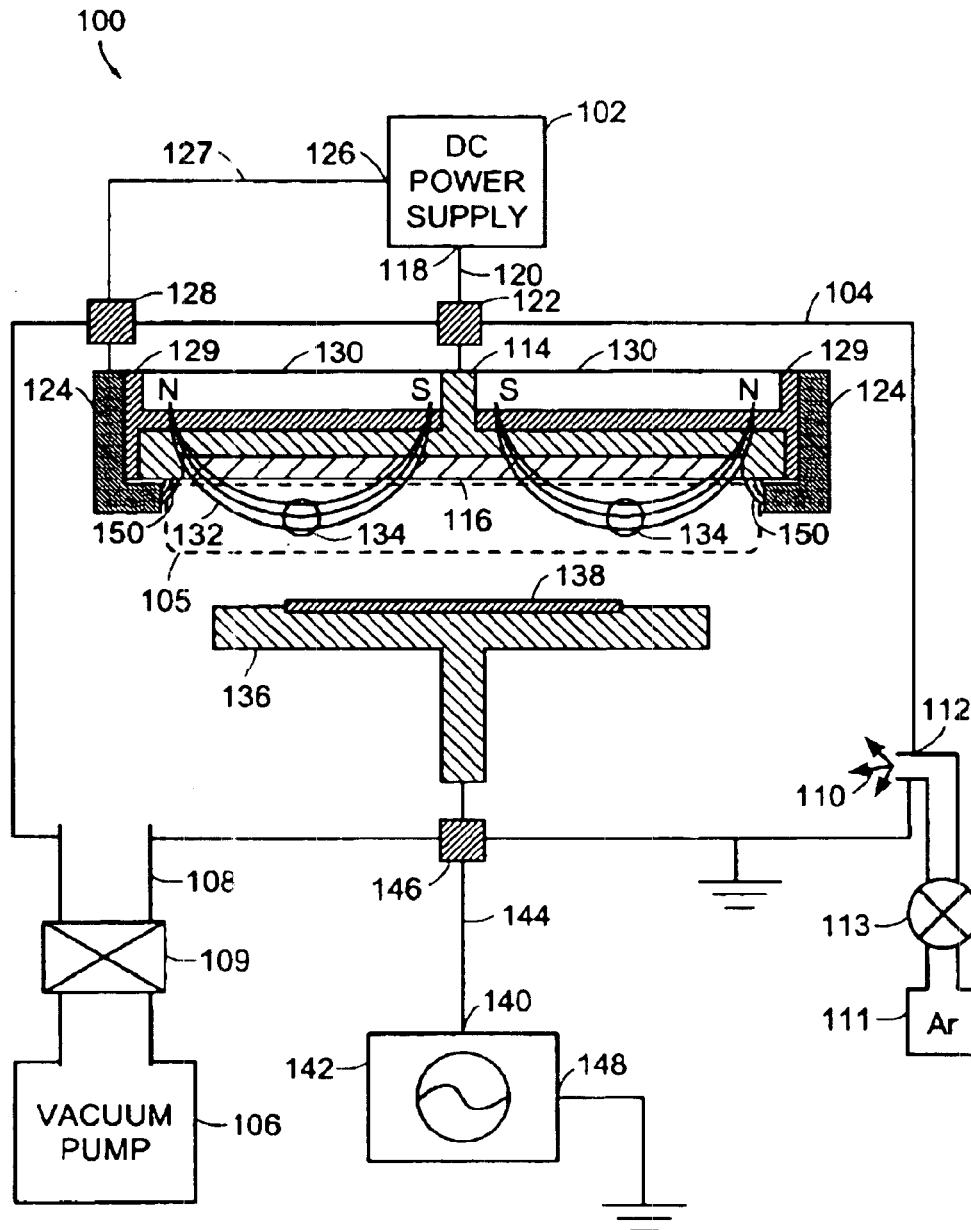


FIG. 1  
PRIOR ART

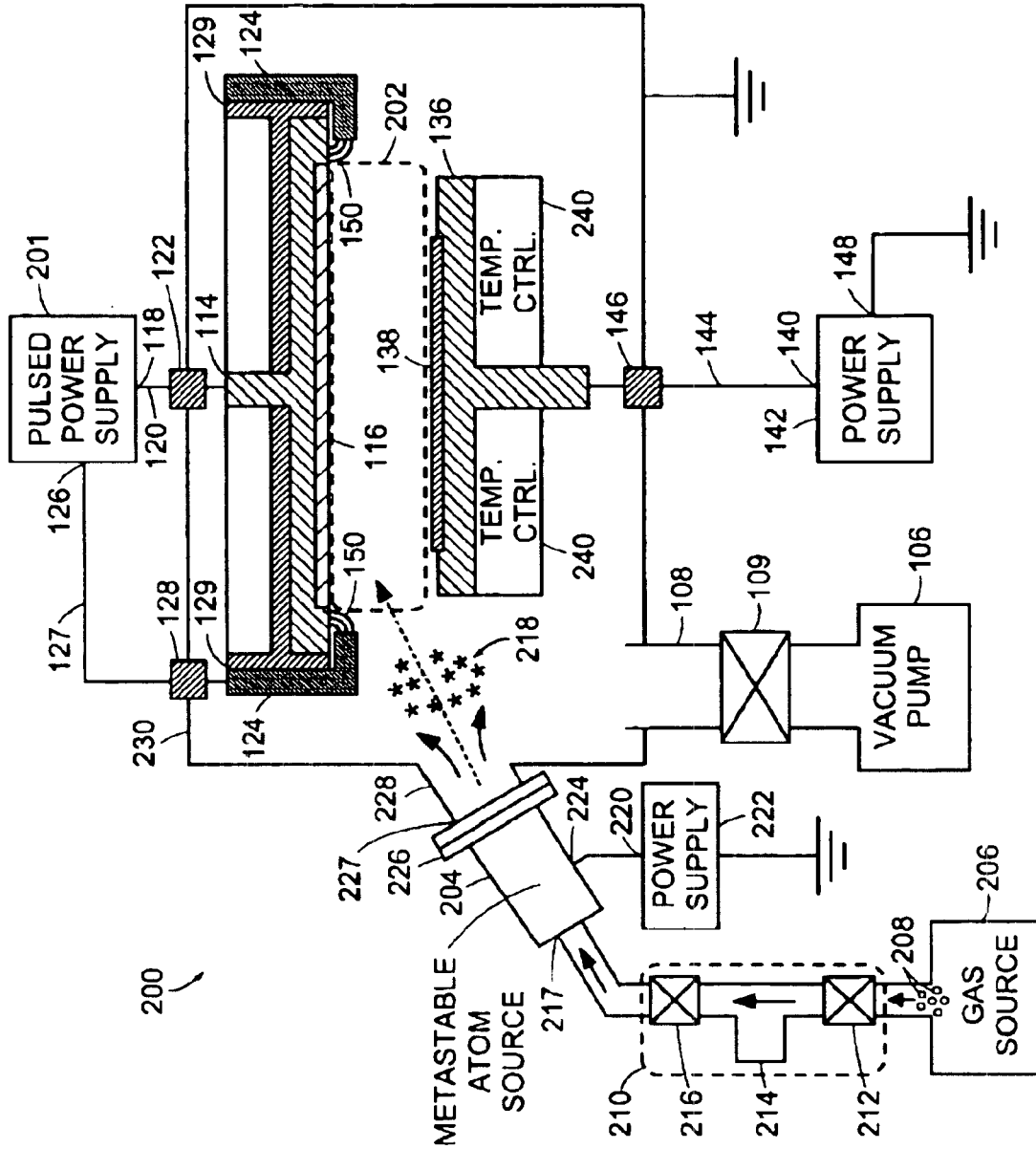


FIG. 2

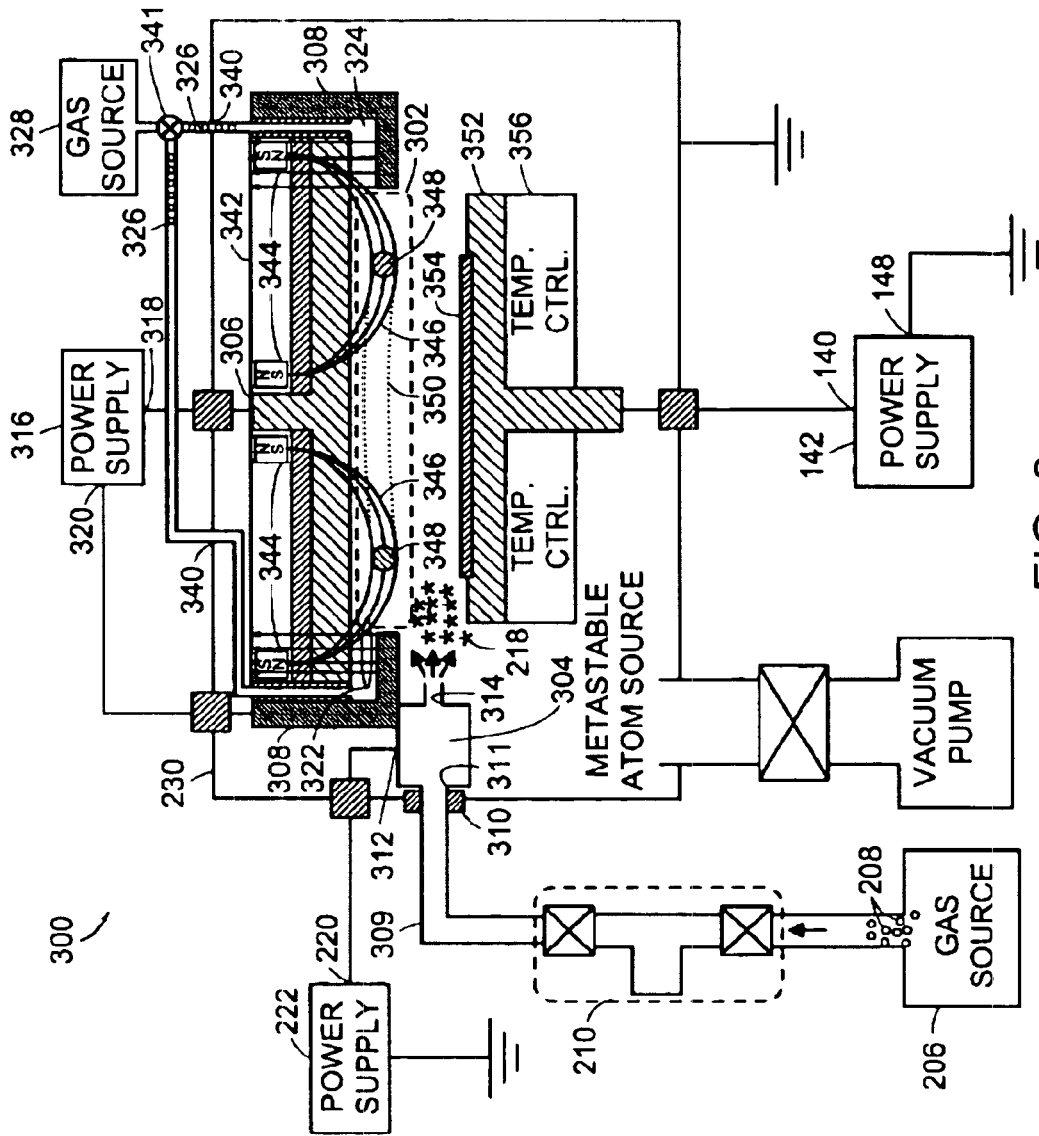


FIG. 3

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