June 2007 Volume 3 Issue 1

Trade Science Inc.

Materials Science

An Indian Journal

Full Paper

MSAIJ, 3(1), 2007 [75-78]

Design And Construction Of Bipolar Pulsed-DC Power Supply For Magnetron Sputtering System

Corresponding Author

Tosawat Seetawan

Department of Physics, Faculty of Science And Technology, Sakon Nakhon Rajabhat University, 680 Nittayo Road, Muang District, Sakon Nakhon 47000, (THAILAND)

Phone: +66-0-4320-2222 Fax: +66-0-4320-2374

E-mail: weerasak1963@yahoo.co.th

Received: 14th January, 2007

Accepted: 19th January, 2007

Co- Authors

Weerasak Somkhunthot[1], Thanusit Burinprakhon[2], Ian Thomas[2], Vittaya Amornkitbamrung[2]

[1]Department of Physics, Khon Kaen University, 123 Mittapap Road, Muang District, Khon Kaen 40002, (THAILAND)

[2]Department of Physics, Faculty of Science And Technology, Sakon Nakhon Rajabhat University, 680 Nittayo Road, Muang District, Sakon Nakhon 47000, (THAILAND)

E-mail : weerasak1963@hotmail.com

ABSTRACT

A bipolar pulsed-dc power supply has been designed and constructed for used in a magnetron sputtering system and for thin film synthesis. The power supply consists of three major parts: (1) Two high voltage direct current (dc) power supplies utilizing a phase control circuit for power delivery, (2) Pulse generator and two power switching circuits, and (3) Feedback circuits for current and voltage controls, displays, and safety measures. For a high level of safety operation, optical connections were employed in the circuit design to isolate between the low and high voltage parts. The constructed power supply was tested using a test load consisting of ten 100 W 250V light bulbs with tungsten filaments connected in series. It was found that the power supply was capable of supplying either symmetric or asymmetric pulsed-dc power of maximum peak-to-peak voltage of 1250 V. The negative and positive pulse widths were selectable between 10-100 μs, with maximum pulse frequency of 25 kHz. This frequency limit is due to the limited speed of the power transistors used in the power switching circuit operating under high voltage. It is anticipated that the constructed power supply can be used as a plasma generator in a magnetron sputtering system for the deposition of oxide thin films such as Al_2O_3, $Na_xCo_2O_4$, ITO and ZnO. This will be further investigated.

KEYWORDS

Bipolar pulsed-dc power supply;
Magnetron sputtering system;
Thin film synthesis;
Oxide thin films.

INTRODUCTION

Magnetron sputtering is one of the physical vapor deposition methods which are widely used in thin film technology. The various types of magnetron sputtering technique are alternating current(ac), radio frequency(rf), direct current(dc), and pulsed-dc. A pulsed-dc magnetron sputtering technique is the latest development of sputtering technology and has many advantages over others. Namely, it is versatile and provides an ability to deposit thin films of oxide compounds such as Al_2O_3, ITO, and ZnO at high deposition rate and to eliminate arcing problems of poisoned target[1]. Since the year 2000, this technique has been a well developed deposition method for coatings and thin films used in research and industrial applications[2-10] .

A key component of a pulsed-dc magnetron sputtering system is a pulsed-dc power supply. Various models of pulsed-dc power supply have been developed and are commercially available[11-12] . However, they are expensive and unaffordable for small scale research. Several researchers have reported attempts at the construction of low-cost pulsed-dc power supplies. For example, Sugimoto et al.[3] developed a pulsed-dc power supply based on inverter technology. They were successful in using the developed power supply to generate pulsed-dc plasma between two parallel plates. It is of interest here to adopt Sugimoto's idea for the development of a pulsed-dc power supply for a magnetron sputtering gun.

In this report, the design and construction of a bipolar pulsed-dc power supply is presented. The current-voltage characteristics of the built power supply tested on a test resistive load are given.

Design and construction

A block diagram of the developed bipolar pulsed-dc power supply for used in a magnetron sputtering system and for thin film synthesis is shown in Figure 1. The power supply consists of three major parts. Firstly, the dc power sources and power controls are a pair of high voltage dc power supplies utilizing a phase control circuit for power delivery. Secondly, a pulse generator and the power switches are a pair of pulsing unit and power switching circuits. Thirdly,

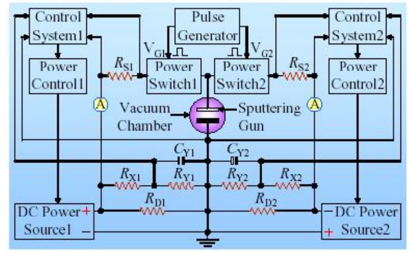

Figure 1 : Block diagram of a bipolar pulsed-DC power supply for magnetron sputtering system.

the control systems are feedback circuits for current and voltage controls, displays and safety measures.

From Figure1, the control systems are capable of varying over the range 0-5V into the power controls. These are used to control the dc power sources so that they can provide the output voltage of 0~1250V, at maximum current of 500 mA. The output voltages are measured by using digital multimeters across the dummy loads R_{D1} and R_{D2}. The power switches are controlled by a pulse generator which is a source of trigger pulses V_{G1} and V_{G2}. They are high speed power MOSFETS with ON/OFF delay times in the order of tens of nanoseconds. When the power switch1 is ON, a voltage from dc power source1($+V_{dc1}$) will be applied to the magnetron. Similarly, if power switch2 is ON, a voltage from dc power source2($-V_{dc2}$) will be applied to the magnetron. However, the two power switches can never be on at the same time. The currents flowing through the power switches are measured by the ammeters (A). The discharge voltage waveform across the magnetron is measured by a×100 high voltage probe. The sense resistors R_{S1}, R_{S2} and R_{Y1}, R_{Y2} provide the feedback voltages into the current limit and voltage control systems, respectively.

The timing sequence of the trigger pulses V_{G1}

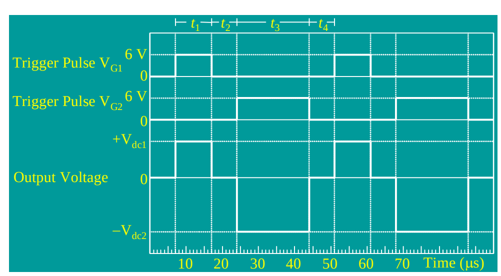

Figure 2: Timing sequence of a bipolar pulsed-dc power supply

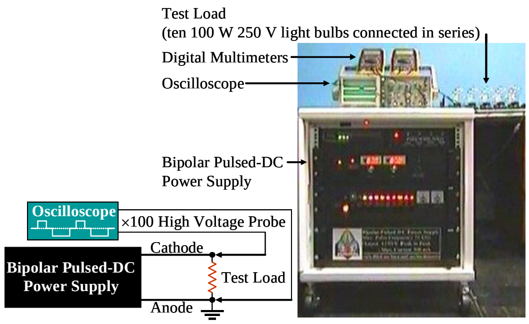

Figure 3: Experimental setup of a bipolar pulsed-dc power supply. (a) Block diagram of experimental setup. (b) Front view of experimental setup.

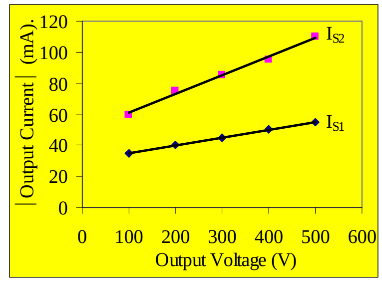

Figure 4: Plot of the current-voltage characteristic of symmetric voltage operation

and V_{G2}, and the output voltages across the magnetron cathode are shown in figure 2.

From figure 2, the trigger pulses V_{G1} and V_{G2} are selectable between 10-100 µs (t_1 and t_3) with maximum pulse frequency of 25 kHz. This frequency limit is due to the limited speed of the power transistors used in the power switching circuit, the high voltage, and circuit capacitance. The values of t_2 and t_4 are chosen so that power switches are never on simultaneously. The output voltage across the sputtering gun (Cathode) consists of the positive pulse (Reverse sputtering duration) and the negative pulse (Sputtering duration), whose widths are determined by t_1 and t_3, respectively. The heights of the positive and negative pulses are equal to the $+V_{dc1}$ and $-V_{dc2}$.

EXPERIMENTAL

The developed bipolar pulsed-dc power supply was tested using a test load consisting of ten 100W 250V light bulbs connected in series as shown in figure 3. The positive and negative pulse widths t_1 and t_3 are fixed at 10µs and 20µs, respectively. The times t_2 and t_4 are kept constant at 7µs. These values of t_1, t_2, t_3 and t_4 give the corresponding pulse frequency of 22.7 kHz.

In experiments, symmetric and asymmetric bipolar pulsed-dc was produced by varying the power modes as follows.

Firstly, for symmetric bipolar pulsed-dc power, the variable voltages between power source $+V_{dc1}$ and $-V_{dc2}$ have to be the same from ± 100 up to ± 500 V.

Next, for asymmetric bipolar pulsed-dc power, the voltage of the power source $+V_{dc1}$ was fixed at 200V and the voltage of the power source $-V_{dc2}$ was varied from –300V up to –1000V.

RESULTS AND DISCUSSION

Symmetric bipolar pulsed-dc power

For symmetric voltage operation, the magnitudes of the power sources $+V_{dc1}$ and $-V_{dc2}$ were equally varied from 100 to 500 V. The output currents I_{S1} and I_{S2} increased from 35 to 55 mA and 60 to 110 mA, respectively. The current-voltage characteristic is shown in Figure 4. From this figure, it can be seen that when variable voltages of power sources $+V_{dc1}$ and $-V_{dc2}$ are varied from 100 to 500 V and –100 to –500 V, respectively, the magnitude of the output current I_{S2} increases twice as fast as that of the output current I_{S1} because the pulse is twice as wide. The waveform of the output voltage for $+V_{dc1}$ = 500V and $-V_{dc2}$ = –500V is shown in Figure 5. This is very close to the expected output voltage waveform given in figure 2.

Asymmetric bipolar pulsed-dc power

For asymmetric voltage operation, the power

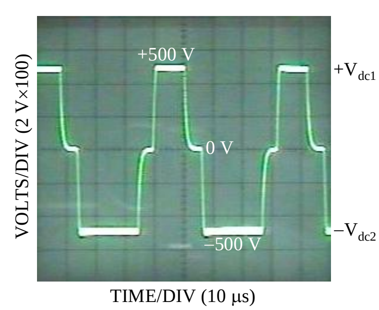

Figure 5: Waveforms of the output voltages for V_{dc1} = 500V and $-V_{dc2}$ = –500 V.

Full Paper

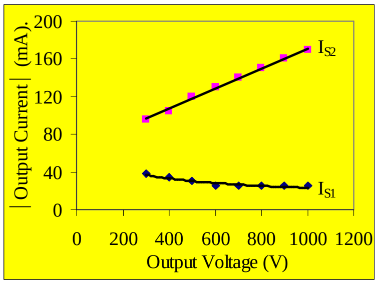

Figure 6 : Plot of the current-voltage characteristic of asymmetric voltage operation

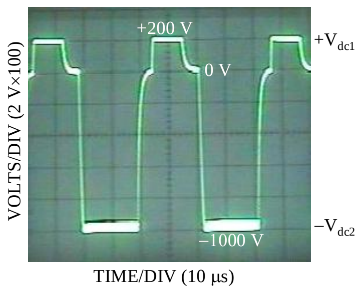

Figure 7: Waveforms of the output voltages for V_{dc1} = 200 V and $-V_{dc2}$ = −1000V.

source $-V_{dc2}$ was varied from −300 to −1000V while the power source V_{dc1} was kept constant at 200V. The resulting current-voltage characteristic is shown in figure 6. From this figure, as the power source $-V_{dc2}$ is varied from −300 to −1000V, the magnitude of the output current I_{S2} increases from 95 to 170 mA, while that of I_{S1} decreases from 38 to 25 mA. Since, the power sources were regulated separately, the reduction in I_{S1} is due the change in the test load resistance with temperature. However, I_{S2} performs as expected. The waveform of the output voltage for $+V_{dc1}$ = 200V and $-V_{dc2}$ = −1000V is shown in figure 7, indicating a good operation in asymmetric mode. This is nearly identical to those obtained from a commercial power supply[2-10].

CONCLUSIONS

A bipolar pulsed-dc power supply which is capable of supplying either symmetric or asymmetric pulsed-dc power of maximum peak-to-peak voltage of 1250 V has been developed. The negative and positive pulse widths are variable between 10-100 μs, with maximum pulse frequency of 25 kHz. This frequency limit is due to the limited speed of the switching circuits under high voltage operations. It is anticipated that the constructed power supply can be used as a plasma generator in a magnetron sputtering system for the deposition of oxide thin films such as Al_2O_3, $Na_xCo_2O_4$, ITO and ZnO. This will be further investigated.

ACKNOWLEDGMENT

This work had financial support from the commission on higher education, faculty of science Khon kaen university, and loei rajabhat university, Thailand.

REFERENCES

[1] G.O.Este, W.D.Westwood; 'Handbook of Thin Film Process Technology', 98/1, Reactive Sputtering, **A5**, 2 1-9 **(1998)**.
[2] H.Gueldner, H.Wolf, F.Eckholz, F.Schrade; Power Electronics Congress, CIEP . VII IEEE International, 365-370 **(2000)**.
[3] S.Sugimoto, M.Kiuchi, S.Takechi, K.Tanaka, S.Goto; Surf.Coat.Technol., **136**, 65-68 **(2001)**.
[4] W.J.Lee, Y.K.Fang, J.J.Ho, C.Y.Chen, S.F.Chen, R.Y.Tsai, D.Huang, F.C.Ho; J.Electron Mater, **13**, 751-756 **(2002)**.
[5] J.L.Andújar, M.Vives, C.Corbella, E.Bertran; Diamond Relat.Mater, **12**, 98-104 **(2003)**.
[6] M.Fink, C.Locker, J.Laimer, C.Mitterer, H.Stori; Surf.Coat.Technol., **188-189**, 281-286 **(2004)**.
[7] A.Belkind, A.Freilich, J.Lopez, Z.Zhao, W.Zhu, K.Becker; J.Phys., **7(90)**, 1-16 **(2005)**.
[8] Th.Dunger, Th.Welzel, St.Welzel, F.Richter; Surf. Coat. Technol., **200**, 1676-1682 **(2005)**.
[9] H.C.Barshilia, B.Deepthi, A.S.Arun Prabhu, K.S.Rajam, Surf.Coat.Technol., **201**, 329-337 **(2006)**.
[10] P.J.Swindells, J.W.Kelly, J. Bradley; Phys., **8(47)**, 1-17 **(2006)**.
[11] Kurt J.Lesker; Company; AE Pinnacle Series, DC Power Supplies., **(2006)**.
[12] MKS Instruments, Inc., DC Power Generators, **(2006)**.