High Power Pulse Plasma Generator for Modulated Pulse Power Sputtering Processes

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ABSTRACT

Modulated pulse power (MPP) sputtering is a variation of high power pulse magnetron sputtering that overcomes the rate loss issue through modulation of the voltage pulse shape, value, and duration. With MPP, the pulse shape and pulse duration directly affect the degree of ionization of the sputtered material. The principals of operation of new arbitrary voltage pulse shape plasma generator will be presented. Method of generating multi step voltage pulses will be discussed.

INTRODUCTION

There are many different power supplies commercially available that can be used for magnetron sputtering applications. Depending on what kind of power supply is connected to the magnetron (DC, pulsed DC, AC, RF power supplies) different type of magnetron discharges can be generated that will provide different conditions for the growing film. The main weakness of these magnetron discharges is the low level of ionization of the sputtered material. As a result, it is difficult to control film structure and film properties. One way to increase the ionization of sputtered atoms is to significantly increase power on the magnetron discharge [1].

PLASMA GENERATOR

A new plasma generator was developed [2-8]. Compared with existing high power pulse plasma generator [1], the new plasma generator can produce arbitrary voltage pulse shape. By choosing the right pulse shape it is possible to generate long high power magnetron discharge with low probability of generating arcs.

Plasma generator consists of a DC unit, a capacitors bank, switch, transformer and output LC circuit. A DC unit is charging the capacitor bank. The capacitor bank is connected with primary of the transformers through the switch. The secondary of the transformers is connected to the output circuit that forms output voltage pulse. Another important difference between the new plasma generator and other pulse power supplies is that proprietary software allows operator direct control of time "on" and time "off" for the switch. The maximum level of the output voltage can be achieved when time 'on' is maximum and time "off" is minimum. The minimum output voltage can be achieved when time "on" is minimum and time "off" is maximum. By generating a sequence with different time "on" and time "off" arbitrary output voltage pulse can be produced. The software allows controlling time "on" and time "off" with accuracy of 0.1-0.2 microsecond. Typical duration of the output voltage pulse shape can vary from 100 microseconds up to 1.5-3.0 milliseconds.

By applying arbitrary voltage pulse shape to the sputtering magnetron a new sputtering technology MPP (modulated pulse power) was developed [2-4]. In MPP, the applied voltage pulse to the magnetron is usually in the range of 0.5-1.5 millisecond and the power density is in the range of 200-600 Watt/cm^2. For example for magnetron with Ti target at power density ~ 300 W/cm^2, ~ 40% of Ti atoms are ionized. Very often the output voltage pulse consists of two different voltage values.

In order to demonstrate the new plasma generator's capabilities of building arbitrary voltage pulse shapes the plasma generator was connected to a circular magnetron with 10 cm diameter Cr target. A conductive substrate with 10 cm diameter was positioned 12 cm away from the target.

On the Figures 1-4 discharge voltage (absolute value) is the top line, discharge current is the middle line and substrate ion current on the bottom line are shown. On the Figure 1 a two stage voltage pulse is presented. In the first stage (low power magnetron discharge) the voltage is ~ 440 V and in the second stage (high power magnetron discharge) voltage is ~ 800 V. The discharge current in the first stage is ~16 A and in the second stage current is ~ 140 A. The ion current coming to the substrate during the first stage is ~ 1 A and ion current during the second stage is ~ 11 A.

On the Figure 2 only one stage (high power magnetron discharge) voltage pulse is presented. The discharge voltage is ~ 800 V. The discharge current is ~ 140 A. The ion current is ~11 A, substrate bias -40 V.

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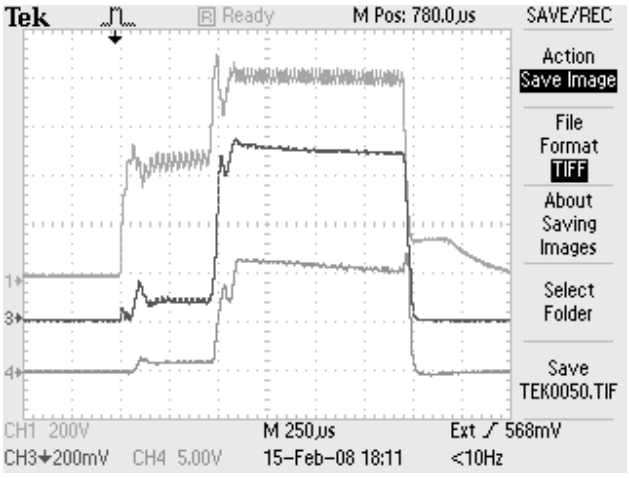

Figure 1: Discharge voltage, current and ion substrate current waveforms from pulsed sputtering with Cr target with pulse duration 1500 microsecond, substrate bias -40 V.

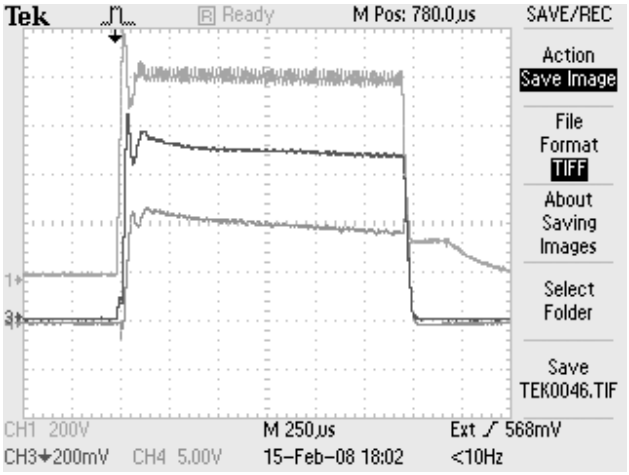

Figure 2: Discharge voltage, current and ion substrate current waveforms from pulsed sputtering with Cr target with pulse duration 1500 microsecond, substrate bias -40 V.

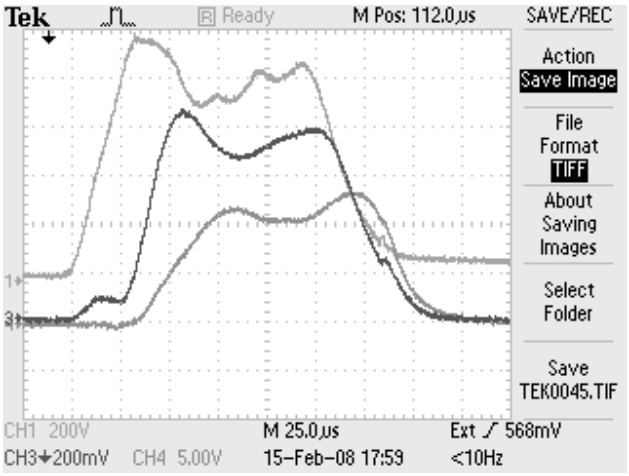

Figure 3: Discharge voltage current and ion substrate current waveforms from pulsed sputtering with Cr target with pulse duration 125 microseconds, discharge bias -40 V.

On Figure 3 only one stage (high power magnetron discharge) voltage pulse is presented. The pulse duration is 125 microsecond. The discharge voltage is ~ 800 V. The discharge current is ~ 140 A. The ion current is ~11 A.

On Figure 4 three stage voltage pulse is presented. The special sequence of time "on" and time "off" was chosen in order to generate voltage oscillations on the output voltage pulse. These oscillations play an important role in getting stable magnetron discharge in reactive sputtering processes.

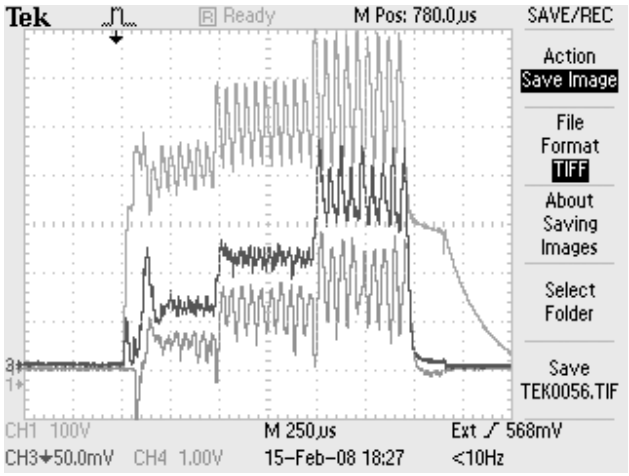

Figure 4: Discharge voltage, current and ion substrate current waveforms from pulsed sputtering with Cr target with pulse duration 1500 microsecond and substrate bias -20 V.

On Figure 5 five stage voltage pulse is presented. Another special sequence of time "on" and time "off" was chosen in order to generate voltage oscillations on the out put voltage pulse.

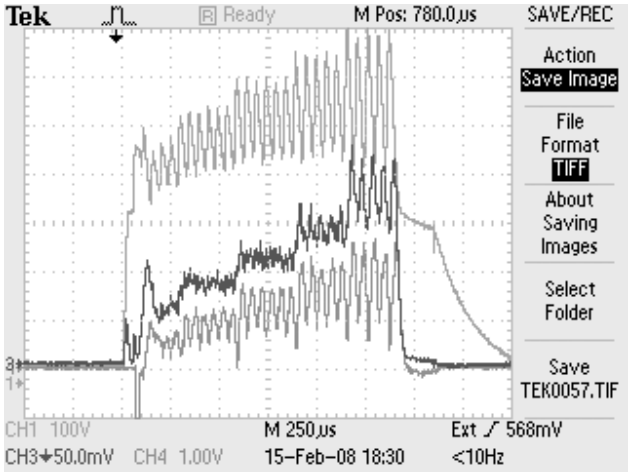

Figure 5: Discharge voltage, current and ion substrate current waveforms from pulsed sputtering with Cr target with pulse duration 1500 microsecond and substrate bias -20 V.

CONCLUSION

A novel pulsed arbitrary voltage pulse plasma generator was developed. This plasma generator can produce negative arbitrary voltage pulse shape. During one pulse the output voltage can be constant or have many different stages. This generator enables a new MPP sputtering technology that provides significant level of sputtered atoms ionization at moderate power densities.

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