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 loss of deposition rate issue through modulation of the voltage pulse shape, amplitude and duration. With MPP, the pulse shape and pulse duration directly affect the degree of ionization of the sputtered material. The principles of operation of a new arbitrary voltage pulse shape plasma generator will be presented. A method of generating multi-step voltage pulses will also be discussed.

INTRODUCTION

There are many different commercially available power supplies 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 magnetron discharges can be generated that will provide different conditions for the growing film. The main disadvantage of these magnetron discharges is that only a low level of ionization of the sputtered material is created. 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 MPP plasma generator was developed [2-8]. Compared with existing high power pulse plasma generators [1], the MPP plasma generator can produce an arbitrary voltage pulse shape.

By developing the right pulse shape it is possible to generate a high power magnetron discharge with long pulse durations and a low probability of generating arcs. The plasma generator consists of a DC unit, a capacitor bank, a switch, a transformer, and an output LC circuit. A DC unit is used to charge 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 the output voltage pulse. Another important difference between the MPP plasma generator and other pulse power supplies is that proprietary software allows operators to directly control the time "on" and time "off" for the switch.
The maximum output voltage is achieved when time "on" is maximum and time "off" is minimum. The minimum output voltage is achieved when time "on" is minimum and time "off" is maximum. By generating a sequence with different time "on" and time "off" values, an arbitrary output voltage pulse can be produced. The software allows control of time "on" and time "off" with an accuracy of 0.1-0.2 microsecond. Typical durations of the output voltage pulse shapes can vary from 100 microseconds up to 1.5-3.0 milliseconds.

By applying power with this arbitrary voltage pulse shape to a sputtering magnetron, a new sputtering technology MPP (modulated pulse power) was developed [2-4]. Typical MPP voltage pulse widths applied to the magnetron are in the range of 0.5-1.5 milliseconds and typical power densities are in the range of 200-600 Watt/cm^2. For example, for magnetron sputtering with a Ti target at a power density ~ 300 W/cm$_2$, ~ 40% of Ti atoms is ionized.
Very often the output voltage pulse consists of two different voltage values.

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

On the Figures 1-4, the discharge voltage (absolute value) is then top line, discharge

current is the middle line and substrate ion current on the bottom line are shown.

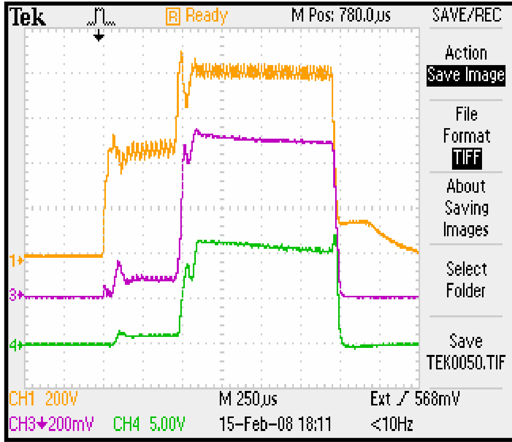

Figure 1: Discharge voltage, current and ion substrate current waveforms from pulsed sputtering with Cr target. Pulse duration is 1500 microseconds, substrate bias is -40 V.

Figure 1 presents a two stage voltage pulse. In the first stage (low power magnetron discharge), the voltage is ~ 440 V and in the second stage (high power magnetron discharge), the 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.

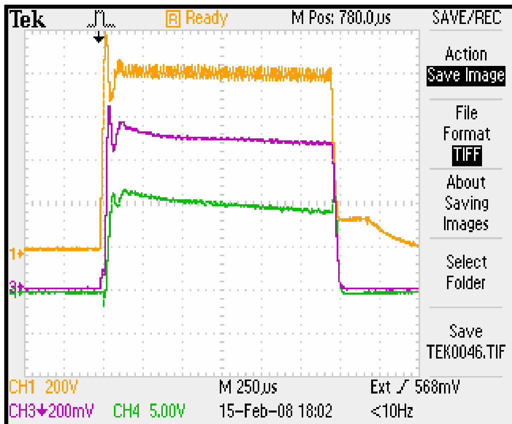

Figure 2: Discharge voltage, current and ion substrate current waveforms from pulsed sputtering with Cr target. Pulse duration is 1500 microsecond, substrate bias is -40 V.

Figure 2 shows a single stage (high power magnetron discharge) voltage pulse. The discharge voltage is~ 800 V. The discharge current is ~ 140 A. The ion current is~11 A, substrate bias -40 V.

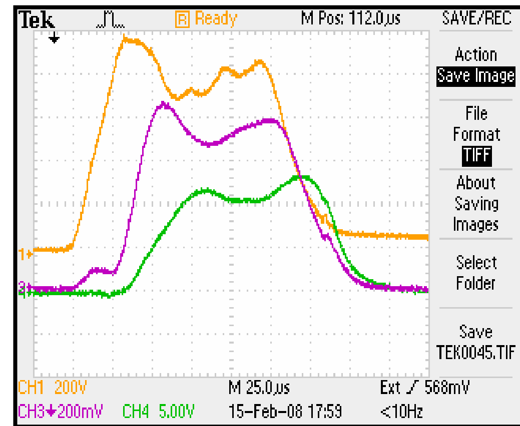

Figure 3: Discharge voltage current and ion substrate current waveforms from pulsed sputtering with a Cr target. Pulse duration is 125 microseconds, substrate bias is -40 V.

On Figure 3 a single 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.

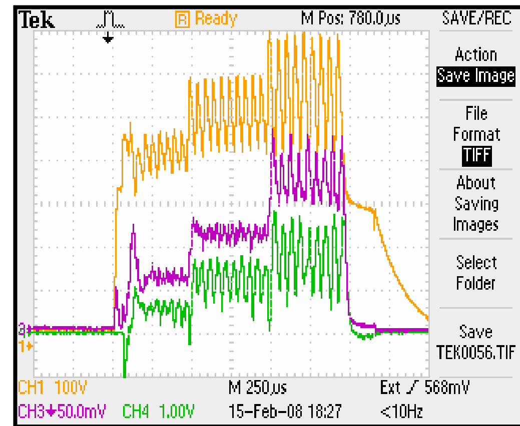

Figure 4: Discharge voltage, current and ion substrate current waveforms from pulsed sputtering with a Cr target. Pulse duration is 1500 microseconds, substrate bias is -20 V.

On Figure 4 a 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 creating a stable magnetron discharge during reactive sputtering processes.

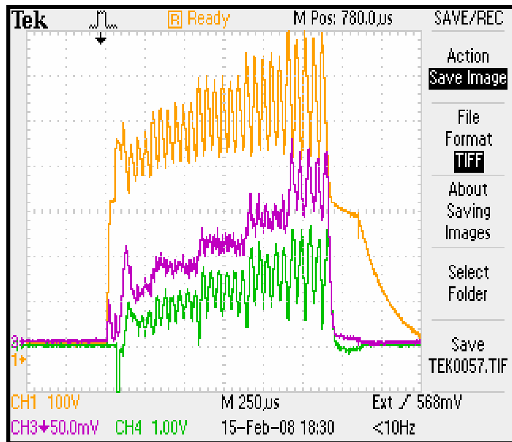

Figure 5: Discharge voltage, current and ion substrate current waveforms from pulsed sputtering with a Cr target. Pulse duration is 1500 microseconds, substrate bias is -20 V.

On Figure 5 a 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 output voltage pulse.

CONCLUSION

A novel pulsed arbitrary voltage pulse plasma generator was developed. This plasma generator can produce negative unipolar arbitrary voltage pulse shapes. During each pulse the output voltage can be constant or have many different stages. This generator enables the new MPP sputtering technology, providing a significant level of sputtered ionized atoms at moderate power densities.

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