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NOVEL PULSED-DC TECHNOLOGY – DUAL USAGE POWER SUPPLY

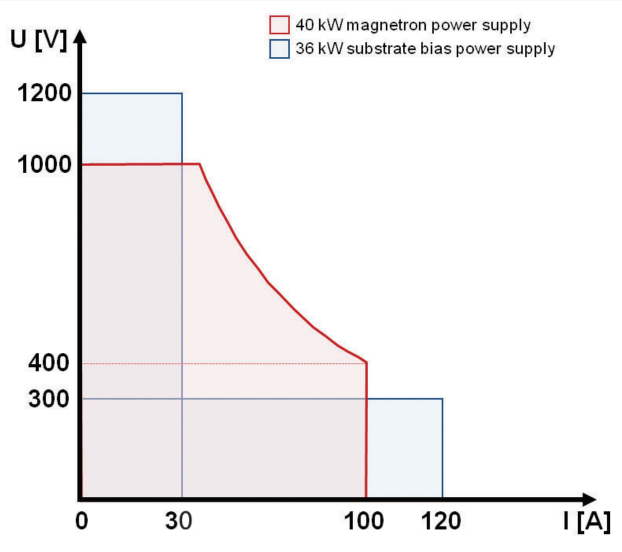

Figure 1: Representation of U-I operation ranges for power supplies developed separately to be used as magnetron or bias power supply

Background

The DC and Pulsed-DC sputtering is one of the most commonly used sputtering technique on the industrial scale. It is used for tool coating, decorative coating, photovoltaic cells production and other. Introduction of the Pulsed-DC technology enabled mass scale production of non-conductive compound coatings deposited by reactive magnetron sputtering. The great advantage of using Pulsed-DC power delivery was a dramatic reduction of arcing on the target surface and thus an improvement of coating quality and a significant prolongation of the operation time without maintenance brakes for mechanical cleaning of the target. With time, the power supply technology allowed to work with pulsing frequency up to 100 kHz as well as to use the reverse voltage during the power brake time to further reduce the arcing probability.

In parallel with the improvements in the power delivery on the target side, the Pulsed-DC technique for substrate polarization (substrate bias) has also been applied as an effective solution for arc suppression on the substrate.

The challenge: effective application of plasma power supply

Despite the fact the DC/Pulsed-DC magnetron or substrate bias power supplies use the same power energoelectronic platform, the application specific requirements led to development of independent unit groups. One of the distinctive features of magnetron and substrate bias power supply units is the applicable operation voltage range. Until now substrate bias power supplies have been prepared to work with two distinct operation ranges: high voltage low current and low voltage high current. The first range is used for plasma cleaning, ion etching or ion implantation and the second range during coating deposition.

Although such situation was strongly ingrained commercially and also TRUMPF Huettinger has both magnetron and substrate bias dedicated power supplies in its portfolio, recent plasma processing development and market trends indicate a need to reconsider this approach. On one hand, both magnetron and substrate bias power supply units need to give much more flexibility for process yield optimization, but also help to provide more cost-effective solutions to the end customer.

So the main question to be answered is: how to achieve high performance, stability and precision without straining your budget?

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The Solution: dual usage power supply

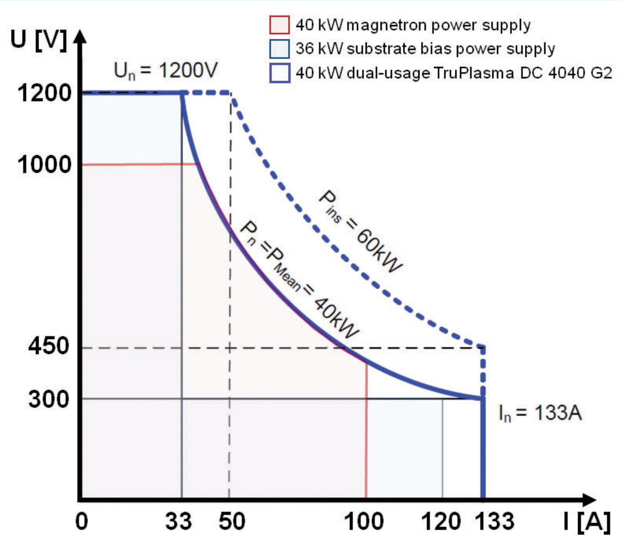

Figure 2: U-I characteristics of TruPlasma DC 4040 G2 dual-usage unit with the range of average power (P_{mean}) and the instantaneous peak power (P_{ins}).

An answer to this question is the new series of TruPlasma DC 4000 G2 power supply. This product line available with average output power of 10 to 40 kW (and above in parallel operation mode) gives an unique, up to now inaccessible, possibility to use one unit either as a plasma source for DC/Pulsed-DC magnetron sputtering or as a DC/Pulsed-DC substrate bias power supply.
What distinguishes the TruPlasma DC 4000 G2 units is the extended current-voltage operation range characteristics. Figure 1 depicts schematically the idea behind the dual-usage power supply. Shapes shaded with different pattern represents ranges of operation for power supply developed separately as magnetron or substrate bias source. Therefore, a magnetron power supply with maximum average power of 40 kW will be limited to maximum 1000 V (400V at 100 A). On the other hand, the substrate bias unit will serve with voltage of 1200V in the high voltage range (current up to 30 A) and up to 300 V in the low voltage operation range to support bias currents up to 120 A.
New applications, such as sputtering from graphite and compound targets, control of reactive processes by voltage regulation or finally higher requirements for bias units working in mixed magnetron source systems, introduce new requirements both for magnetron as well as bias power supplies which cannot be fulfilled with the standard approach. As depicted in Figure 2 the new dual usage Pulsed-DC TruPlasma DC 4000 G2 characteristics meets these requirements by covering the operation range of both typical magnetron power supplies as well as units used to substrate polarization. All 10, 20, and 40 kW units can provide up to 1200 V with maximum current of 8.3, 16.6 and 33 A, respectively. For voltage ≤300 V new 10, 20, and 40 kW units can work with maximum currents of 33, 66.5 and 133 A, respectively. Therefore, TruPlasma DC 4000 G2 units can be applied as bias power supplies in applications where a relatively high bias current as it is the case in ionized plasma processes utilizing filtered arc deposition [1] or HIPIMS ion implantation [2] is used. An extended voltage operation range up to 1200 V is also beneficial when the TruPlasma DC 4000 G2 unit is used as a magnetron power supply: firstly higher accessible voltage promotes faster and highly repeatable re-ignition of plasma, and secondly, it allows to work with high voltage materials such as graphite.
An extended I-U characteristics at high voltage is not the only novelty. TruPlasma DC 4000 G2 can also work at process voltage and current values previously not accessible, at least not without complex hardware adjustments i.e. change of capacitor bank. Important is that the whole operation range is available both in magnetron and bias operation mode of the TruPlasma DC 4000 G2 units and the selection between modes is done by selecting one option ("Magnetron"/" Bias") on the device operation panel or in the dedicated user interface software PVDPower.
To bring a complete picture of the U-I operation range of TruPlasma DC 4000 G2 series it must be clear differentiated between the nominal average power and the maximal instantaneous power during

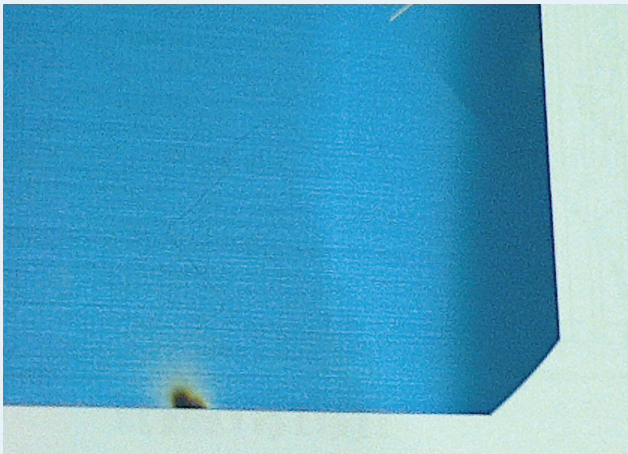

Figure 3: An example of damaged Si wafer during ITO deposition by DC reactive sputtering process (before using Pulsed-DC).

pulse. This difference is depicted schematically in Figure 2. In order to provide requested average power independently on the pulsing frequency the instantaneous power delivered in each pulse can reach up to 150% of the nominal power of the TruPlasma unit, which in the case of TruPlasma 4040 G2 is 60 kW. This in turn guarantees delivery of nominal average power and to keeping high deposition rates at different frequency and duty cycle settings.

Reactive magnetron sputtering of demanding materials

The dual usability of TruPlasma DC 4000 G2 is not the only unique feature of these power supplies. Operation in DC as well as in Pulsed-DC mode with frequency 2 – 100 kHz and adjustable duty cycle up to 98% (100% in DC mode) is available. In addition, both in magnetron and substrate bias mode, during the Pause Time a positive reverse voltage can be applied which controlled voltage: up to 30% of process voltage, not higher than 100 V and length: from 0 μs up to the whole duration of the Pause Time.
Broad range of operation parameters of TruPlasma DC 4000 G2 series has already demonstrated its strength in various applications. To refer to one of the most spectacular one the deposition of Indium Tin Oxide (ITO) for Si solar cells will be briefly described as an example.
The use of Pulsed-DC technology is a common method used to reduce arcing probability on the target surface during reactive sputtering [3, 4]. A Pause Time in power delivery additionally combined with reverse voltage results in an attraction of electron from the target vicinity and neutralization of the accumulated positive charge on the poisoned target surface [5]. Comparable effect of a charge build-up can also happen on electrically isolated elements such as sample holders and is responsible for formation of arcing at the boundary between sample holder and substrate. Such effect was observed during the deposition of ITO film in Ar/O_2 atmosphere on Si wafers for PV application. Initially film deposition was performed from DC powered rotatable cylindrical ITO targets in an in-line system for Si photovoltaic cell production. In this particular case, setup cost savings made with application of simple DC power delivery method were soon in vain because of high failure rate of wafers due to arcing on wafers during ITO deposition. Due to the electrical separation of the wafer holder and wafer from the electrical ground of the system and plasma power supplies, charge build-up on the edges of wafers resulted in serious arcing and damaging of wafers as shown in Figure 3. To eliminate complex and expensive solution which required external circuit for voltage measurement at the wafer holder application of Pulsed-DC TruPlasma DC power supplies was chosen as the best solution. The flexibility of frequency and Pause Time setting were used to find the possibly lowest pulsing frequency and minimum Pause

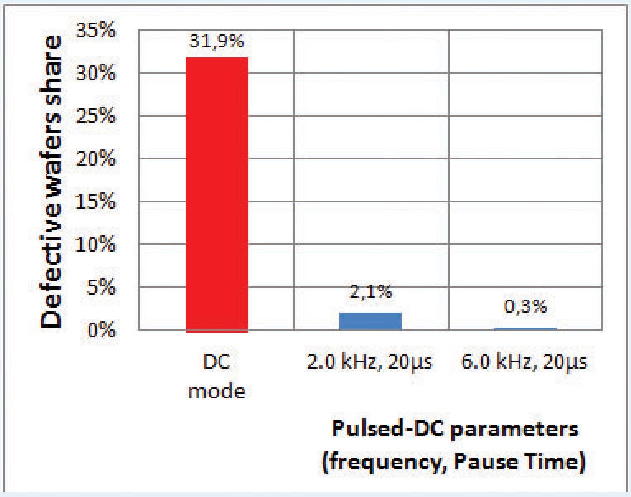

Figure 4: Comparison of Pulsed-DC settings effect on the production yield of ITO deposition on Si wafers.

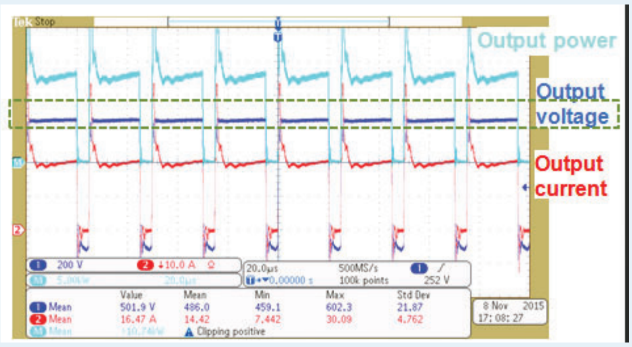

Figure 5: Example of voltage and current shape of Tru-Plasma DC 4020 G2 operated in BIAS mode.

Time required to eliminate arcing. The data presented in Figure 4 evidence the expected positive effect of Pulsed-DC application. As the process quality measure the ratio of the defective wafers was plotted as a function of power supply settings: frequency and Pause Time. Already use of minimal pulsing frequency of 2 kHz and an Pause Time of 20 µs results in reduction of faulty wafers in a batch by factor of ten. By further increase of pulsing frequency the possibility to neutralize the charge accumulated on the wafers and wafer carrier during the Pause Time also increases. As a result, at 6 kHz and 20 µs Pause Time a statistically acceptable level of faulty wafers was reached allowing the release of the system for mass production.
Therefore, these data not only supports previous reports on the arc suppression by the introduction of Pulsed-DC for magnetron sputtering but extends its applicability as a tool for effective reduction of charging effects on floating substrates.

Application of Pulsed-DC substrate bias

Substrate biasing is a common technique used together with the DC or Pulsed-DC magnetron sputtering. It is used for plasma cleaning, shallow ion implantation to improve coating adhesion and for tuning morphology and mechanical properties of protective coatings. In all these applications the idea of using substrate bias is to extract ions from the plasma bulk and increase their energy in the potential drop at the surface. Since the applied bias voltage has an influence on the ion energy distribution (IED) the stability of the bias voltage level is a key factor.
Figure 5 presents series of voltage and current waveforms of the TruPlasma DC 4020 G2 unit used in the "Bias" mode. Two unique features of TruPlasma DC 4000 G2 units can be concluded from the graph: (i) very good stability of the bias voltage during the pulse for high and for very low voltages (< 50 V), as well as (ii) negligible voltage overshoot at the On-to-Off and Off-to-On voltage pulse. By analogy to the effects observed in Pulsed-DC magnetron operation, elimination of voltage overshoots and oscillations at Pulse On-to-Off and Off-to-On cycles is necessary for weakening the rapid changes of plasma parameters (i.e. electron temperature) [6], and in turn more precise and uniform control of ion impingement on the biased substrate. The high stability of bias voltage is of great importance in plasma cleaning applications where the possibility to use voltage up to 1200 V enhances cleaning performance, thus improving the processing speed. On the other hand, if a low voltage bias is used, a precise control of the voltage level during the pulse is beneficial for uniform coating parameters. To meet such requirements the TruPlasma DC 4000 G2 units provide advanced regulation algorithms which reduces voltage ripples as depicted in Figure 6. In this particular case of 20 V bias voltage the ripples (peak-to-peak) are less than 2 V. To our knowledge, this is the lowest available value in the up-to-date substrate bias power supplies on the market.

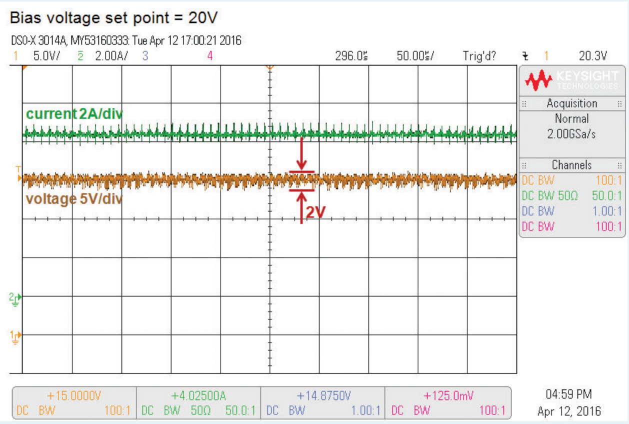

Figure 6: The stability of TruPlasma DC 4000 G2 power supply units in Bias mode. An example of operation at bias voltage of 20V is shown.

Conclusion

The new generation of the Pulsed-DC power supplies TruPlasma DC 4000 G2 is a smart combination of TRUMPF Huettinger experience in DC and Pulsed-DC power delivery.
For the first time one unit can be used as a magnetron power supply or substrate bias power supply. At the same time all advanced functionalities such as wide frequency and duty cycle settings or highly effective arc suppression are available to the user independently whether the unit is used to deliver required power to magnetron or substrate bias. Therefore, these units are not only an interesting alternative for process engineers as a tool to enhance the stability of the process (elimination of arcing) or improve the production yield (wide range of operation settings). Dual usability of TruPlasma DC 4000 G2 is also an interesting product for investors to reduce cost of ownership by unification of used power supply types on plasma systems.

References

[1] A. Anders, „Energetic Deposition Using Filtered Cathodic Arc Plasmas," Vacuum, 67 (2002) 673–686.

[2] A. Ehiasarian, P. Hovsepian, L. Hultman and U. Helmersson, „Comparison of microstructure and mechanical properties of chromium nitride-based coatings deposited by high power impulse magnetron sputtering and by the combined steered cathodic arc/unbalanced magnetron technique," Thin Solid Films, 457 (2004) 270-277.

[3] P. J. Kelly and J. W. Bradley, „Pulsed magnetron sputtering – process overview and applications," Journal of Optoelectronics and Advanced Materials, 11 (2009) 1101 - 1107.

[4] J. Musil, P. Baroch, J. Vlcek, K. Nam and J. Han, „Reactive magnetron sputtering of thin films: present status and trends," 475 (2005) 208-218.

[5] X. Mao, B. Cai, M. Wu and G. Chen, „Deposition of aluminium oxide films by pulsed reactive sputtering," J. Mater. Sci. technol., 19 (2003) 368 - 370.

[6] J. Bradley and T. Welzel, „Physics and phenomena in pulsed magnetrons: an overview," J. Phys. D: Appl. Phys., 42 (2009) 093001.

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