The C-TVA Plasma Source – A Chemical Vacuum Thin Film Deposition Tool

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ABSTRACT

It is presented here for the first time the capability of a new plasma source based on Thermionic Vacuum Arc plasma (TVA), to deposit oxide, nitride, oxinitride and other chemical compound thin films. This plasma is called Compact-TVA (C-TVA) and uses gas and metal precursors in a compact set-up which allows continuous and unlimited deposition, with no target poisoning, in contrast to magnetron sputtering, for example. The C-TVA plasma does not use buffer gas and, as it does not fill the vacuum chamber, low temperature deposition can be made. The source is very versatile in terms of deposition parameters, allowing metal/ceramic multilayer structures and even continuous band-gap structures to be obtained in one load. Also, its energetic ions (tens to hundred eV) determine formation of compact films. Self sustaining thin films (micro-foils) could therefore be obtained. These assets make C-TVA a very powerful plasma source in terms of applicability, from green microelectronics to medicine.

Keywords: thin film deposition, continuous band-gap, oxinitride, self-sustaining film, solar cell materials

1 INTRODUCTION

Thermionic Vacuum Arc (TVA) is a confined plasma source in vacuum using solid precursors which sends energetic metal ions (tens to hundreds eV) and neutrals to non-biased substrates placed away from its plume, forming a compact, particle-free film. Characteristic to this type of plasma source are the high voltage (of a few keV) and low discharge current (of arround 1-2 A).

The first work on TVA is documented in a paper in 1966 [1]. Later studies within the same laboratory were concerned with both TVA plasma diagnostics and characterization of deposited metallic films [2-6]. A sister plasma source is GasTVA (G-TVA) which uses gas/liquid precursors instead of solid ones [7].

The Compact arc plasma (C-TVA) presented here was designed for use with solid and gas precursors simultaneously, allowing deposition of chemical compound thin films like oxides, nitrides, oxinitrides, carbides etc.

The set-up allows continuous and unlimited deposition, with no target poisoning, in contrast to magnetron sputtering [8].

Multilayer nanostructuring of metal/ceramic films ca be obtained.

Deposition of particle-free films is achieved due to the use of an electron source which gently ignites the plasma by collision with the precursor atoms and/or molecules. Very low film roughness is thus achieved.

The films obtained by C-TVA can be used in electronics, sollar cells, chemical and/or mechanical corrosion resistance, medicine (biocompatibility), decoration etc.

2 MAIN APPLICATIONS OF C-TVA PLASMA

The unique combination of features in C-TVA, such as high ion energy, no buffer gas, independent tuning of plasma operating parameters and gentle plasma ignition offers immense possibilities to synthesize new materials.

Figure 1 presents an image of the C-TVA plasma ignited in Ti and nitrogen. As can be seen, this plasma is localized and the samples are arranged above the plasma plume.

In Figure 2, a typical I-V characteristic of a TVA plasma ignited in Ti vapors is presented. In the first part of the characteristic, the metal is heated-up until evaporation. At a certain temperature, the plasma is ignited in the vapors created due to evaporation. At this point, a sudden drop of the voltage is obtained. From this point on, the discharge voltage is set and a further power imput is driven to an increase of the current.

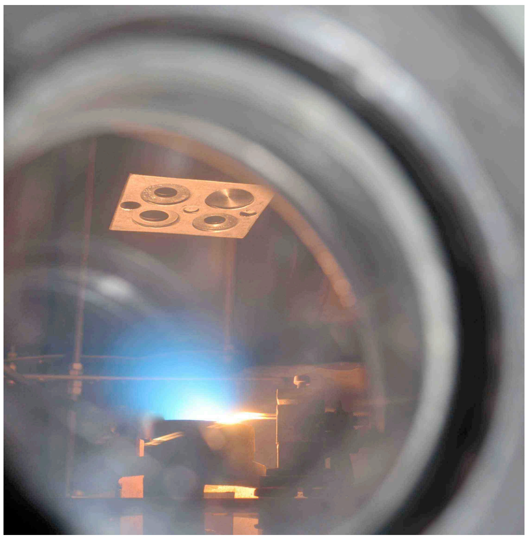

Figure 1: The C-TVA plasma ignited in Ti vapors and nitrogen

The specific design of TVA plasma enables independent tuning of ion energy and current density. The ion energy is proportional to the discharge voltage while the discharge current can be separately varried via the electron emission current of the electron source.

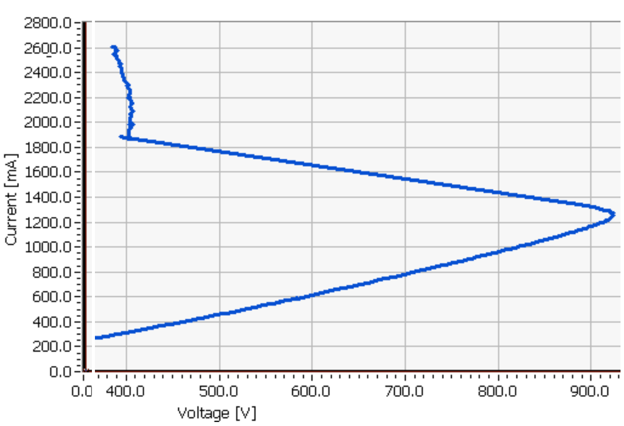

Figure 2: Typical I-V characteristic of the TVA plasma ignited in Ti vapors

Different discharge voltages and consequently various ion energies can be set for the same current, as shown in Figure 3.

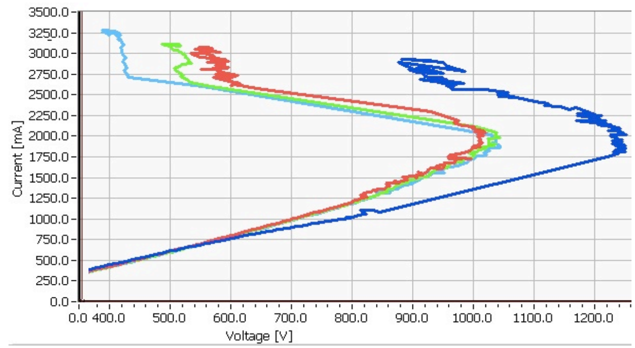

Figure 3: Variation of discharge voltage for the same ar current

Addition of different gases to the metal plasma changes the operation parameters but full control of the required ion energies and current densities is still possible. Figure 4 shows that the same voltage/ion energy can be obtained for different precursor combinations.

This plasma source can become a valuable tool for industrial applications and may also be a new source of inspiration in scientific research.

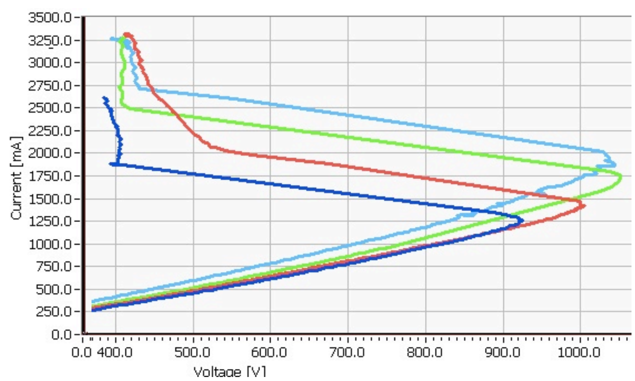

Figure 4: Variation of discharge current for similar voltages

2.1 Deposition of Chemical Compound Thin Films

Chemical compound thin films can be synthesized with C-TVA using the appropriate solid material (metal or graphyte) and gases. By tuning the plasma operating parameters, variable bandgap multilayers and even continuous band-gap layers can be deposited in a single load using C-TVA.

Chemical compounds of refractory metals can be deposited using this plasma.

Figure 5 shows different chemical compound thin films obtained with this plasma source. Both interference colors as well as pure chemical ones were synthesized.

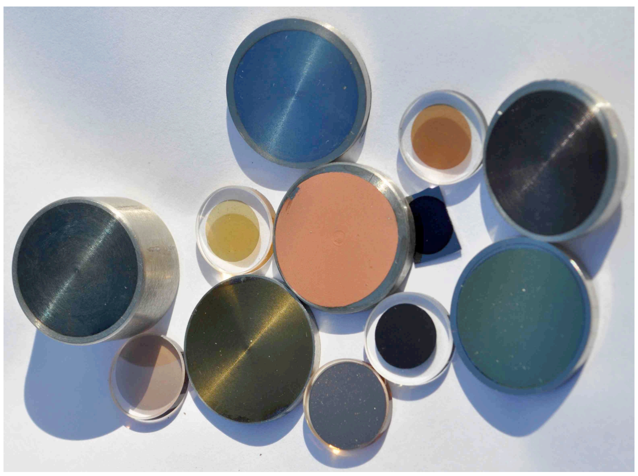

Figure 5: Compound thin films obtained with C-TVA on different substrates.

2.2 Sythesis of Self-sustained Films

Ions of energies of tens or even hundred eV impinging on the growing film determine formation of a very dense film on the substrate. Due to their high density, the films can be lifted-off, self sustaining films as thin as 1 micron can thus be obtained (seen in Figures 6 and 7).

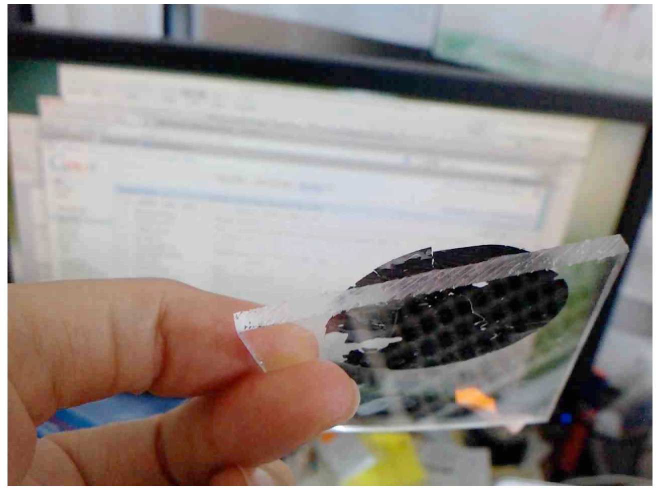

Figure 6: Diamond Like Carbon self-sustaining film (2.1 microns thickness).

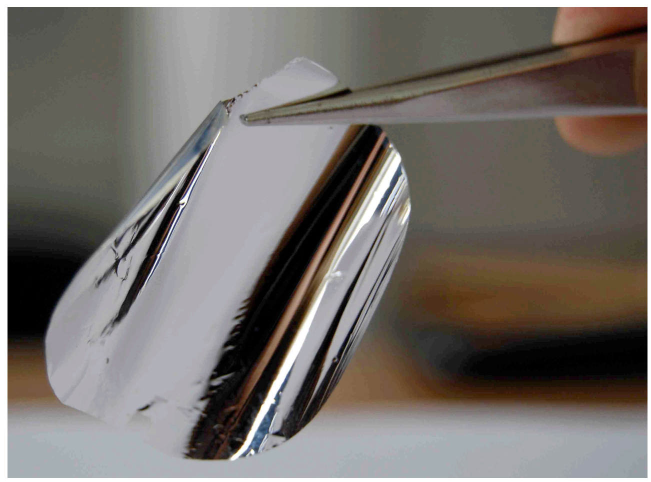

Figure 7: Self-sustaining Ag foil (1.4 microns thichness)

Not using buffer gas, there is no heat conduction and therefore there are no gas inclusions in the film.

2.3 Room Temperature Processing

Not filling the vacuum chamber, the TVA plasmas offer the opportunity to make thin film deposition on thermally sensitive materials.

Low temperature processing is an important asset of the TVA plasma in general and of C-TVA in particular.

Copper was deposited on a wing of a bee to demonstrate this feature (Figure 8).

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Figure 8: Copper film deposited on a bee wing using TVA.

Sheets of paper were deposited with different thin films using this plasma (Figure 9). The material remained intact.

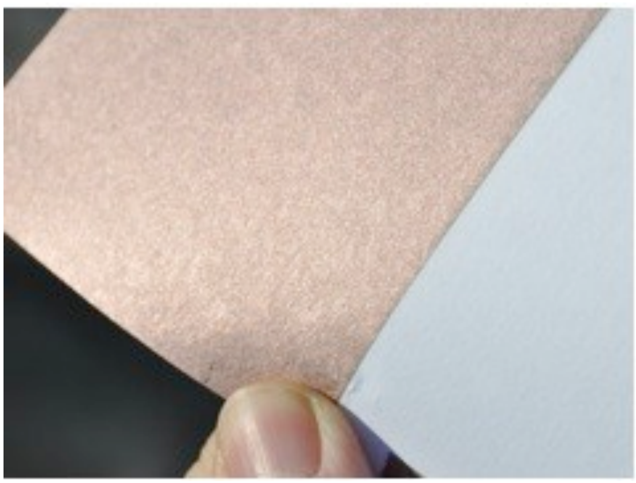

Figure 9: Paper sheet deposited with a copper film using TVA

This asset opens an important field of applications of TVA in green microelectronics especially.

3 CONCLUSION

C-TVA is a versatile plasma deposition tool for dense, low roughness ceramic films and multilayers of controlled thickness and composition.

Due to the unique design, characteristics of the ions and neutrals obtained with this plasma (such as ion energy, density, kind of particle) are not simultaneously obtained in other thin film deposition tools. The ions arrive at the substrate with high energies without applying a bias, the ion to neutrals ratio is relatively low compared to other plasmas and the film is formed by atoms of the material of interest with no addition of buffer gas atoms.

These characteristics influence the properties of the films that can be synthesized with C-TVA, thus providing a unique tool for thin film deposition.

This plasma source can be involved and developed for a large range of applications including green microelectronics, medicine, autmotive industry and many more.

Acknowledgments

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REFERENCES

[1] I.Popescu et al, Brit. J. of Appl.Phys, 17, 129, 1966.
[2] C.Surdu-Bob et al., J. Phys. D, 41/13, 132001, 2008.
[3] C.Surdu-Bob et al., Diam.Rel.Mat., 17, 1625, 2008.
[4] G.Musa, C.Surdu-Bob, J.Optoel.Adv.Mat 9/4, p.867, 2007.
[5] C. Surdu-Bob, et al., J.Optoel.Adv.Mat., 9, p.2932, 2007.
[6] Surdu-Bob, et al., J.Optoelectron.Adv.Mat., 9/8, 2660 (2007).
[7] G.Musa, C.Surdu-Bob, Patent No.123002/2010 (OSIM Romania).
[8] R. Arvinte et al., Appl.Surf.Sci, 257, 9120, 2011.