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Large area microwave coating technology

M. Liehr *, S. Wieder, M. Dieguez-Campo

Applied Films GmbH and Co KG, Alzenau, Germany

Abstract

Microwave plasma enhanced chemical vapour deposition (PECVD) of thin films is the preferred technology when highest deposition rates are desirable. However, large area applications have always suffered from poor film thickness uniformity and unacceptable variations of thin film properties. Coaxial plasma line sources in various arrangements have recently proven their ability to overcome most limitations, which prevented microwave PECVD of becoming a mainstream technology in the field of large area coatings. In this article, the advantages and the potential of the coaxial plasma line sources and suitable vacuum processes are discussed in detail.

Keywords: Organometallic vapour deposition; Plasma processing and deposition; Solar cell; Silicon oxide

1. Introduction

Large area vacuum coating on very large substrates is nowadays almost entirely in the hands of magnetron sputtering. Physical vapour deposition (PVD) by magnetron sputtering has matured over the years, achieving coating uniformities of better than 2% over 3.2 m of coating width. However, deposition rates are relatively low and therefore other vacuum process technologies may be favourable when it comes to applications requiring a film thickness in the micrometer range and above. Plasma enhanced chemical vapour deposition (PECVD) offers a solution for ceramic, semiconductive and polymeric thin film applications. A typical PECVD process principally comprises a variety of gaseous feedstock and carrier materials supplied to a vacuum vessel and a power source to sustain a plasma discharge. The power source can be either DC electrical or electromagnetic with frequencies ranging from AC, acoustic, radio frequency, VHF to the Radar range depending on the application. Plasma uniformity, density and temperature are decision-making criteria as well as ion energies.

Since high plasma densities and low ion energies are key issues for efficient PECVD processes, microwave energy appears to be the best choice for high rates. In spite of being capable of achieving plasma electron densities well in the 10^{11} cm^{-3} range and electron temperatures around 10 eV, the specific design of a microwave power-driven large area plasma source can be troublesome and not lead to the desired results. The key problem is how to sustain a uniform and steady plasma discharge over areas much larger than the wavelength of the applied microwave power. Here, the most prominent obstacle on the way to success is certainly the design of the atmosphere-to-vacuum interface. Unlike magnetised microwave plasmas employing the electron–cyclotron–resonance (ECR) effect for efficient plasma heating, low-pressure discharges will usually ignite at the very location of microwave power encountering suitable vacuum conditions. Since microwave plasma discharges will generally be dense and hot they will effectively prevent the microwaves from propagating further into the vacuum vessel, thus making it difficult to produce large area plasma discharges and also imposing a substantial heat load on the interface material. Attempts to overcome this basic problem can be found in the literature and various patents have been filed on this matter. Many plasma source designs have obviously been derived from radar antenna principles, which have been studied well in the past and are therefore well understood and documented [1,2]. However, the transfer of the design and functionality of a radar antenna

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* Corresponding author.
E-mail address: mliehr@eu.appliedfilms.com (M. Liehr).

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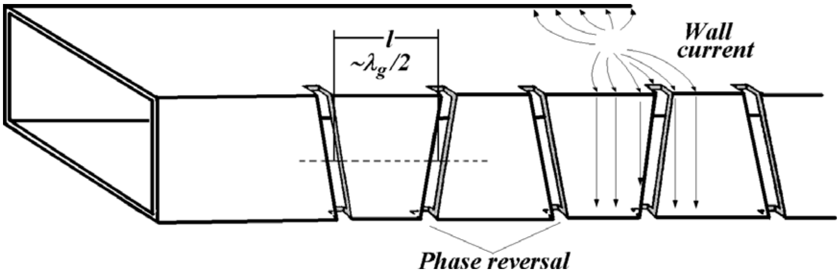

Fig. 1. Rectangular waveguide section with edge shunt slots. Spaced about half a wavelength apart and phase reversed at inclining angles the slots should provide equal net power output.

into a vacuum vessel with electrically conductive walls always proved to be problematic. While radar antennas are designed for free range operation with only a very small fraction of the emitted power being reflected by objects back into the radiating structure quite substantial amounts of the emitted power can be reflected from both the metallic surfaces of the vacuum vessel and the plasma discharge [3]. Hence, the original calculation and design of the radiating elements of a radar antenna may be rendered useless in the case of high levels of fluctuating reflected power in close proximity.

A typical example of a radar antenna is shown in Fig. 1. A microwave transmission line such as a rectangular waveguide would have been used and slots in either the broad or the narrow side of the waveguide would have been cut. By intersecting electrical wall currents of the basic microwave propagation mode a certain fraction of the propagating power would have been radiated from the slot and subsequently supplied to the plasma discharge after having passed the atmosphere-to-vacuum interface. Since the propagating power in the waveguide would have been attenuated accordingly after having passed a slot, the neighboring slot would have to have a slightly stronger coupling to radiate the same net amount of microwave power towards the plasma. The entire slotted section of the waveguide would have produced a very uniform radiation pattern, theoretically resulting in a uniform plasma discharge. However, if any of the slots had experienced a high amount of reflected power for whatever reason this power would have propagated backwards through the slot in both directions of the rectangular waveguide and modified the incoming power levels for the remaining slots. Eventually, this would have caused some of the slots radiating more and others less compared to the nominal values having lead to an undesired and sometimes even unsteady plasma distribution. The isolation of the radiating elements from the power transmission line would technically be possible but make such a plasma source an extremely expensive tool.

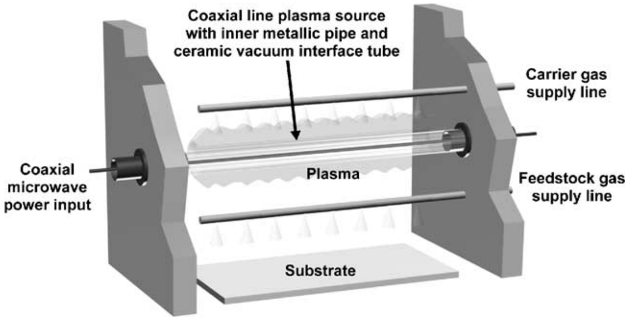

Fig. 2. The principal layout of the coaxial line plasma source in semi-remote plasma arrangement.

Therefore, a different type of launch structure for microwave power needed to be found.

2. The coaxial line plasma source

The breakthrough on the way to a spatially sustained microwave discharge over areas much larger than the wavelength of the applied microwave power was certainly the both brilliant and simple idea to replace the rectangular waveguide and its troublesome discrete radiating elements by making the electrically conductive plasma part of a coaxial transmission line. Microwave power is supplied to a vacuum vessel by a coaxial transmission line in the transversal electromagnetic (TEM) wave mode. Inside the vacuum vessel, a tube manufactured from a dielectric material, which acts as an atmosphere-to-vacuum interface, as described in Fig. 2, replaces the outer conductor of the coaxial line.

Since the material should be heat-resistant and should have a low dielectric loss tangent either quartz or alumina appears to be the most suitable materials. Microwave power can pass through the tube material and ignite a plasma discharge of high radial symmetry circumjacent the tube surface. Having replaced the metallic outer conductor of the coaxial transmission line by a (electrically conductive) plasma discharge a surface wave sustained linearly extended discharge is obtained [4–6]. The microwave power prop-

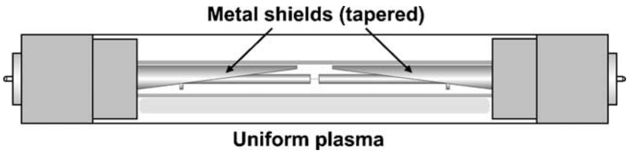

Fig. 3. Coaxial line plasma source (side view) with tapered metal shields behave for improved plasma uniformity. The shield behaves like outer conductors of a coaxial transmission line.