HIGH POWER MICROWAVE PLASMA PROCESSING

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ABSTRACT

Some results of the research on microwave plasma processing are given, concerning the modification and cleaning of surfaces, plasma activated CVD, synthesis of nitric oxides and preliminary work on microwave plasma spraying.

1. INTRODUCTION

Microwave plasma is well known as suitable tool low pressure and low power chemical and material processing. Its application in the range of higher pressures is not that frequent because this requires higher power levels from microwave sources. Typically, when using commercial microwave sources, power level available does not exceed 0.1 - 0.5 kW. This is why atmospheric pressure microwave discharges find their wide application only as low power micro - plasma generators for chromatography detectors or light sources in spectroscopy. Commercial generators of higher powers are not so easily available, moreover operation with high power microwave can be hazardous and calls for trained personnel and precautions to radiation problem. Also microwave technique at high power is somewhat specific in comparison to the more popularly known RF or DC techniques. Those factors, among others, have limited progress of the research in field of high power microwave plasma. Application of high power microwaves in industry
/ drying, glueing, cooking etc. have led to significant development of microwave tubes/magnetrons, klystrons / and there is number of tubes available today with power level of 100 kW and more. This suggests a new look at microwave plasma as competing tool for material processing.

2. EXPERIMENTAL

Research on microwave plasma is carried out by Plasma Technology Group since 10 years and a set of unique equipment had been constructed [1]. The research is concerned with diagnostics and modelling [2,3] as well as with applications. Most frequently microwave plasmatrons are constructed basing on the coaxial or rectangular waveguides with fundamental mode of wave propagation [1,2]. More sophisticated devices use circular waveguides or different resonant cavities. Both coaxial and waveguide plasmatrons were described in the Proceedings of ISPC-2 and 5. Those plasmatrons have been used in one-step nitric oxides production from atmospheric air. Results achieved in that process were good enough to discuss proposals of the semi-industrial scale. It has been found that the process efficiency is higher when using rectangular waveguide plasmatron which assures higher electric field strength in the plasma and this way stronger departure of plasma from equilibrium / non LTE plasma /. Overequilibrium, typically 5%, concentrations of NO_x were detected during repeatable experiments. Further research has confirmed that best efficiency of synthesis occurs when power level in a single plasma column was ranging within 1.3 - 1.6 kW. At higher power levels plasma column diameter becomes larger and plasma can not be efficiently penetrated by the electromagnetic field and only external plasma layers can be maintained in the non-LTE condition. This suggests that multi-plasma applicators rather then single high power units should be used when scaling up the device. Advantage of such approach is possibility of an immediate extrapolation of the results obtained in laboratory with technical feasibility of improved impedance matching of the multi-head system to microwave generators. So then the reported earlier low energy consumption of
7 - 11 kWh/kG of NO\textsubscript{x} could be repeated on a larger scale / 0.5 - 1. MW /.

One of interesting applications of microwave plasma is connected with modification of the polyestral surfaces. This process has been carried out under reduced pressure using the set up shown in fig.1.

![Diagram](image)

**Fig.1.** Microwave plasma stand for polyestral cord and glass fiber treatment.

1-microwave generator, 2-measuring and matching circuitry, 3-microwave discharge cavity, 4,5-vacuum chambers /M-motor drive/

6-vacuum pump, 7-manometer, 8-flow meter.

After about 0.7 - 0.9 sec. treatment of polyestral cord passing through the section with plasma it's adhesive properties has been enhanced up to 8 times as compare to the initial material [4].

Yet another low pressure has been carried out the main goal of which was high speed surface cleaning of glass fibers from after - production impurity deposits like oils and paraffins. Those deposits, although necessary in the production process, are undesirable afterwards. The essential for cleaning process was rapid oxidation of the deposits in oxygen or air plasma and then removal of reaction products / mainly CO\textsubscript{x} / outside the plasma by means of a small gas flow [5]. Energy consumption for the process as low as 6 x 10\textsuperscript{-2} kWh/m\textsuperscript{2} has
been achieved, that means more than 100 times reduction as compare to the traditional arc plasma or glow discharge treatment.

For the both lately mentioned processes a special industrial plasma applicator has been developed that enables generation of long \(0.5 - 2\) m plasma column at power level \(0.5 - 2\) kW. Among the successful semi-industrial applications of microwave plasma preparation of the silica preform for fiber optics production is now under final step of the development. This CVD process is carried out both at atmospheric and reduced pressures using oxygen as plasmagen gas and chlorides of halogens as reactants that after decomposition and oxidation form layers deposited inside the substrate tube / see ISP-5 Proc. /. Power level to be applied depends on operating pressure, speed of longitudinal plasma cavity movement and whether the layers are going to be immediately consolidated or not. Typically at atmospheric pressure power level did not exceed \(2.4\) kW. Recently a new magnetron has been installed with maximum power level of \(6\) kW. However, after Philips, some reduced pressure and reduced power experiments are planned using an external long furnace supporting simultaneous glassing of the oxide layers. The pilot experiments with microwave plasma-activated CVD gave very promising results. Deposition efficiencies of \(SiO_2\) and \(GeO_2\) are reaching a \(100\%\).

Fibers made from prepared preforms exhibit low attenuation of \(2.5 - 3\) dB/km / at \(\lambda = 0.85\) \(\mu m\) /.

Research has also been started on application of microwave plasma to spraying of metal coatings. One of the problems that had to be solved was efficient injection of particles into the microwave discharge. This has been accomplished by combining a small inductive RF plasma with the coaxial microwave cavity as shown in fig. 2. Without the inductive plasma support the E-type microwave discharge becomes constricted at the tip end and part of the particles tends to bypass column of microwave plasma. When applying RF inductive currents the temperature distribution in the tip region gets flat, and particles can be easily injected into the plasma along it's axis. A \(25\) kW microwave power stand is still being under construction and only some preliminary experiments have been
performed by using a combination of 1.5 kW / 5 MHz / and 2.4 kW / 2450 MHz / generators. These experiments fully confirmed the idea of enhanced injection efficiency of particles into the plasma. At the same time, microwave plasma column can be created long enough to assure sufficient residence time for injected particles.

Fig. 2. Combined RF - Microwave plasmatron

REFERENCES


