

PLASMA



PROCESSING UPDATE

A newsletter from the

**Facilitation Centre for Industrial Plasma Technologies
Institute for Plasma Research**

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Editor's Note

Magnetron based sputter deposition technique is one of the most widely used and well studied PVD techniques. This technique is extensively used in the semiconductor industry, for antireflection coatings on glass in optical industry, for the manufacturing of optical waveguides etc. One of the important advantages of this technique is its ability to deposit even those materials which have very high melting points. However, it may pose problems to deposit alloys or compounds from a single target, due to the differences in the sputtering yields of the composing elements. Such problems could be solved by starting with elemental targets (of which the alloy is made of) and by controlling the operating parameters one can try to get the desired alloy composition in the deposited film. In one of such attempts, at FCIPT, it was tried to study the effect of operating parameters on the composition of the deposited film. Mr. R. S. Rane has elaborated more on this.

Tin Oxide (SnO_2) is one of the first TCOs to receive significant commercialization, due to its high transparency and very good electrical conductivity. Because of its excellent properties, it finds applications in various areas. At FCIPT, a study was undertaken to investigate the optical, structural and electrical properties of SnO_2 films deposited by Plasma Assisted Thermal Evaporation process (PATE). More details are presented by Mr. Chetan Jariwala.

A prototype Plasma Pyrolysis system, developed by FCIPT, was installed at GCRI, Ahmedabad. Recently, the emissions of this system were analyzed and the results have been presented and discussed by Dr. S. K. Nema. Further, Dr. Balasubramanian has explained about synthesis of carbon nanotubes.

Editor : *Alphonsa Joseph*

Co-editor : *A. Satyaprasad*

Conference Presentations from FCIPT

Name of the Author	Topic	Date	Place	Conference
Dr. S. K. Nema	Safe Disposal of Organic waste and Energy Recovery using Plasma Pyrolysis Technology	11-12 June 2010	CII, APTDC, Hyderabad	National Symposium on Municipal Solid Waste Management
Nirav Jamnapara	Fusion Materials Development	12-13 July 2010	Ahmedabad	NFP-Industry interaction Workshop
Dr. S. K. Nema	Safe Disposal of Medical & Plastic Waste and Energy Recovery Possibilities using Plasma Pyrolysis Technologies	26-29 July 2010	Putra World Trade Center, Kuala Lumpur, Malaysia	6 th International Conference on Combustion, Inceneration/Pyrolysis and Emission Control AND 2 nd International Conference & Exhibition on Waste to Wealth

About FCIPT

Facilitation Centre for Industrial Plasma Technologies

The Institute for Plasma Research (IPR) is exclusively devoted to research in plasma science, technology and applications. It has a broad charter to carry out experimental and theoretical research in plasma sciences with emphasis on the physics of magnetically confined plasmas and certain aspects of nonlinear phenomena. The institute also has a mandate to stimulate plasma research activities in the universities and to develop plasma-based technologies for the industries. It also contributes to the training of plasma physicists and technologists in the country. IPR has been declared as the domestic agency responsible in INDIA to design, build and deliver advanced systems to ITER (International Thermonuclear Experimental Reactor), to develop nuclear fusion as a viable long-term energy option.

The Facilitation Centre for Industrial Plasma Technologies (FCIPT) links the Institute with the Indian industries and commercially exploits the IPR's knowledgebase. FCIPT interacts closely with entrepreneurs through the phases of development, incubation, demonstration and delivery of technologies. Complete package of a broad spectrum of plasma-based industrial technologies and facilitation services is offered. Some of the notable achievements of FCIPT are: plasma nitriding of industrial components to increase wear resistance and hardness, coating of quartz-like films on brassware to inhibit oxidation and tarnishing, thermal plasma technologies for waste treatment, plasma processing for textile industries, deposition of TiN coatings to increase abrasion resistance, deposition of amorphous silicon coatings for anti-reflection properties, etc. The Centre has process development laboratories, jobshops and material characterisation facilities like Scanning Electron Microscope, X-ray Diffractometer, Microhardness testing facilities, which are open to users from industry, research establishments and universities.

This newsletter is designed to help you keep abreast with the developments in the important field of plasma assisted manufacturing and to look for new industrial opportunities. We would be very happy to have you write to us on ways of improving this service or visit us for further discussions.

Please visit our website: <http://www.plasmaindia.com> or <http://www.ipr.res.in/fcipt>

Deposition of Alloy/Compound Coatings using a Twin-Magnetron Co-sputtering system

Mr. R. S. Rane



Magnetron Sputtering is an extremely flexible coating technique that can be used to coat virtually any material viz. Metals, alloys, compounds, insulators etc. Sputtering is basically removal of atoms of a given target material, by energetic bombardment of its surface layers by ions or neutral particles. In the magnetron based sputtering techniques, magnetic fields are used to increase the efficiency of the sputtering process. This technique has several advantages over other vacuum based coating techniques such as thermal evaporation and electron beam evaporation. Some of the advantages include: high deposition rates, ease of sputtering any metal, alloy or compound; high purity films, extremely high adhesion of the deposited films, ability to deposit coatings on heat-sensitive substrates, excellent uniformity on large-area substrates (e.g., architectural glass), ease of automation etc. This technique, being highly flexible and advantageous, has found a large number of commercial applications ranging from microelectronics fabrication to simple decorative coatings and food packaging.

Deposition of metal coatings using magnetron sputtering is a straight forward process. However, when we need to deposit an alloy or a compound coating, it's a little complicated. We can choose to sputter a single target of the same composition as that of the alloy or compound which needs to be deposited. However, in this case, because of variation in the sputtering yields of different elements present in the alloy/compound, it would not be possible to obtain the coating of same composition as that of the alloy/compound target. Alternatively, the same coating could be deposited by simultaneously sputtering those elemental targets (separate) of which the coating is consisted of. A process of this kind is known as co-

sputtering, and when this is performed in the presence of a reactive gas, it is called reactive co-sputtering. Co-sputtering process is used when controlled mixtures of materials are required in the form of a thin film. Further, this technique offers a lot of flexibility in depositing coatings with non-stoichiometric compositions, and to deposit such complex compounds or alloys which would be difficult or sometimes impossible to be available as single targets.

At FCIPT, we have designed and developed a twin-magnetron sputtering system, in which two different target materials could be simultaneously sputter deposited, and the electrical power to each of these targets could be controlled independently. The schematic diagram of the developed system is shown in figure 1 and a three dimensional rendered-view of the same system is shown in figure 2. The system consists of a stainless steel vacuum chamber and a pumping system that includes rotary and diffusion pumps. The vacuum chamber has a provision to place two unbalanced magnetrons such that these magnetrons are inclined by 39° with respect to the vertical axis of the vacuum chamber, as shown in figure 1. These magnetrons were water cooled and were independently powered by two D.C. Power supplies. A silicon wafer was used as the substrate, on which the coating was deposited, and was placed 10 cm down from the target plane. The positioning of the two magnetrons and the substrate was such that the sputtered flux combines at the substrate plane and forms the required alloy/compound on the substrate as shown in figure 1.

In this study, we had used Titanium (Ti) and Aluminum (Al) as the target materials and the objective was to deposit Ti-Al alloy. Further, it was also tried to investigate the dependency of varying power (to each magnetron) on compositional variations in the deposited thin films. In the initial set of experiments, the dependency of the deposition rate on the magnetron power was studied separately with individual targets of Ti and Al, and by using an in-situ thickness monitor. The results of this study are shown in figure 3. By using this data, the required magnetron power (for each target) was estimated in order to maintain the required Ti-Al composition in the deposited thin film. A series of

experiments were carried out in which the atomic % of Al was varied from 10% to 50% in the Titanium film. The deposited film was characterised by EDAX to find out the elemental composition (atom %). The results of these experiments are summarized in table 1. The EDAX results of the experiments 1 and 2 are shown in figure 4. A typical cross sectional SEM micrograph of the deposited thin film is shown in figure 5. The results clearly show that by controlling the magnetron power of each target, the compositions of the deposited film can be controlled.

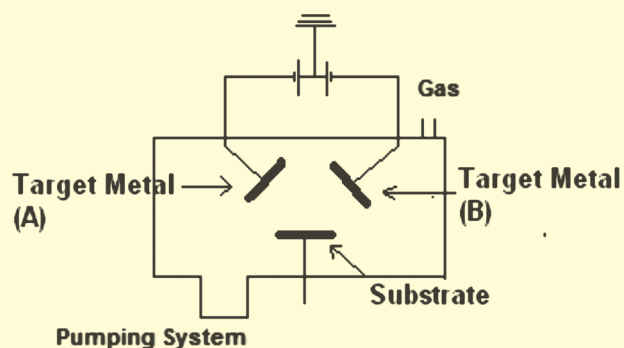


Fig.1: Schematic diagram of the experimental system

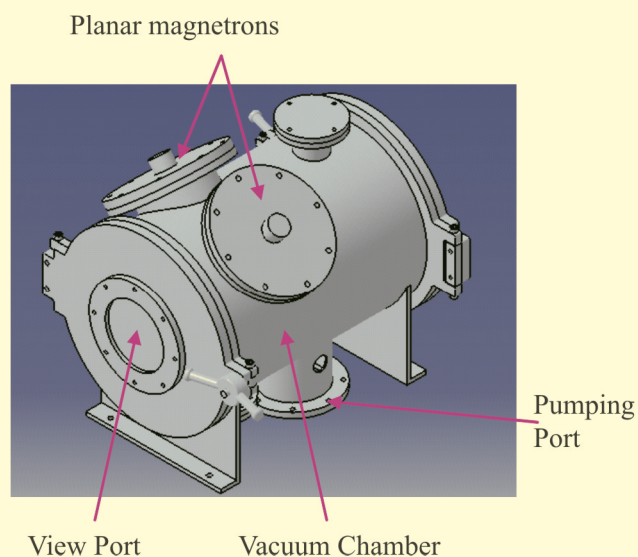


Fig.2: 3D rendered view of the same experimental system

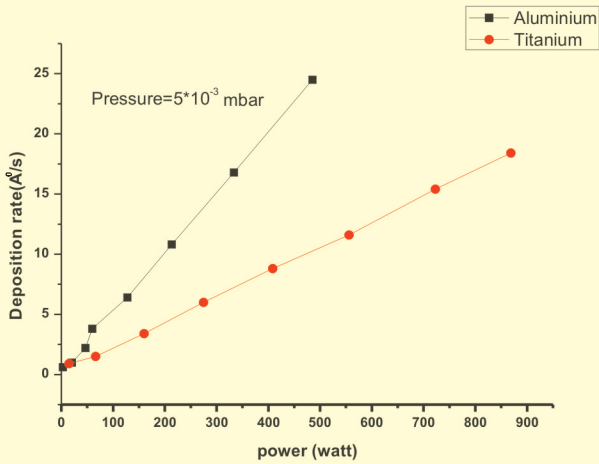


Fig.3: Plot showing the dependency of deposition rate on the magnetron power

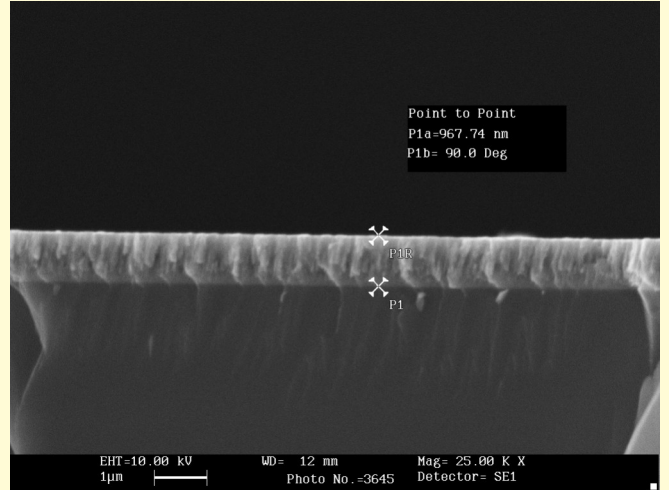


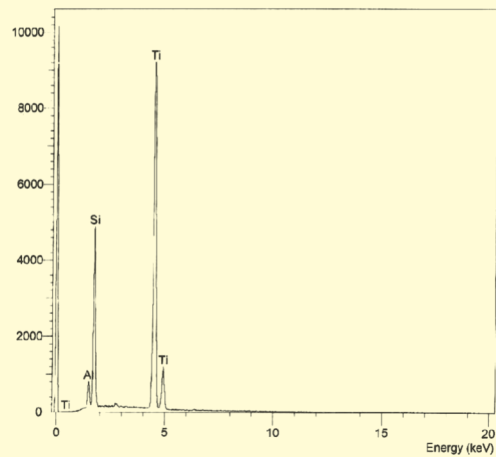
Fig. 5: SEM micrograph of a typical cross-section Ti-Al deposited thin Film

Table 1: Summary of the experimental details and results

Exp. No.	Required composition (atom% Al-Ti)	Aluminium Target power (watt)	Titanium Target power (watt)	Obtained composition (atom% Al-Ti) By EDAX
1	10-90	20	400	8-92
2	20-80	20	200	18-82
3	30-70	20	120	29-71
4	40-60	45	190	36-64
5	50-50	45	80	55-45

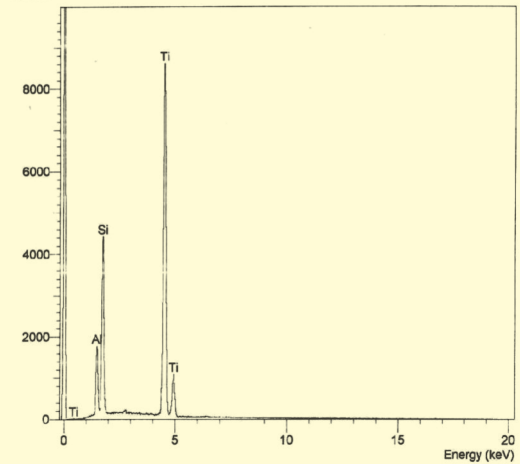
Conclusion: A twin magnetron co-sputtering system that could be used for alloy/compound deposition was designed and developed at FCIPT. It was observed that the atom percentage of the metals in alloys could be controlled by controlling the power of individual metal targets.

Operator : LEO
Client : All ISIS users
Job : Demonstration data SILI detector
Ti-Al on Si-s#2,30.04.10,area (02/05/10 10:32)



A [Ti-Al (90-10%)]

Operator : LEO
Client : All ISIS users
Job : Demonstration data SILI detector
Ti-Al on Si-s#2,03.05.10,area (02/06/10 10:25)



B [Ti-Al (80-20%)]

Fig. 4: Results of the EDAX analysis for experiments 1 (A) and 2 (B) (Table 1)

Tin Oxide Thin Film Processing by Plasma Assisted Thermal Evaporation using RF Oxygen Plasma for Photovoltaic Applications

Mr. Chetan C. Jariwala

1. INTRODUCTION



Tin oxide (SnO_2) thin films are n-type semiconductors with a rutile tetragonal structure and have a wide band gap of 3.6 eV. SnO_2 is the first transparent conductor to receive significant commercialization, due to its high transparency and very good electrical conductivity. Owing to its low resistivity and high transmittance

properties, SnO_2 is the most attractive and preferred Transparent Conducting Oxide (TCO) for various applications such as window layers in solar cells (fig.1), heat reflectors, liquid crystal displays, various gas sensors, photo-detectors, and protective coatings etc. [1-5]. Further, recently, various nano-sized metal oxides as anode material for Li-ion batteries have been extensively studied due to their excellent electrochemical properties and high recycling rates. Among them, tin oxides such as SnO , SnO_x ($1 < x < 2$) and SnO_2 have been identified as most promising anode materials due to their much higher reversible capacities and better stability than graphite [6]. SnO_2 films have been fabricated on several different substrates by numerous techniques such as Physical Vapour Deposition (PVD) including thermal evaporation [7], DC and RF magnetron sputtering [8,9], Chemical Vapor Deposition (CVD) [10], sol-gel dip coating [11], spray pyrolysis [12] and plasma based evaporations [13] etc.

In the present work we have grown SnO_2 thin films by Plasma Assisted Thermal Evaporation (PATE) process using RF (13.56 MHz) O_2 plasma. The detail optical,

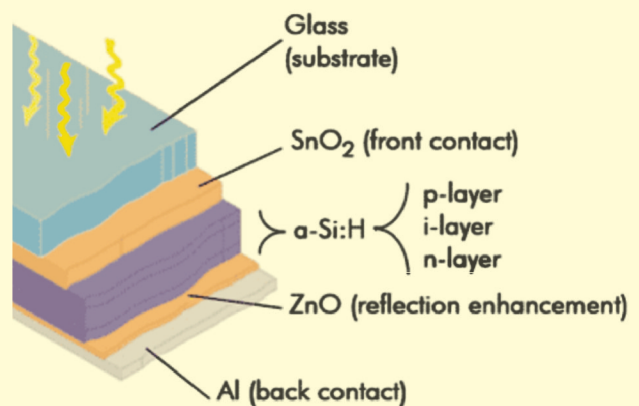


Fig. 1: Schematic diagram of a-Si:H thin film solar cell shows a single p-i-n junction with SnO_2 as front contact as well as window layer and Aluminum as back contact.

structural, surface and electrical analysis of the deposited films has been performed using optical transmission spectroscopy, X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM) and Four-probe setup respectively.

2. EXPERIMENTAL

SnO_2 films are deposited by evaporating metallic tin powder (99.99%) on various substrates such as glass, polished SS samples and silicon wafers. The substrates are externally heated to temperatures between 250 and 350° C. The tin (Sn) powder is placed in a Molybdenum boat, which is resistively heated by a dc power supply. The substrate holder is placed above the boat and the distance between these two is maintained at 10 cm. In order to enhance the reaction between the evaporating species of Sn and O_2 , the O_2 plasma is generated in the region between the boat and substrate holder. A triode based RF power source was developed in house, and a matching network (MN) was also designed to couple the maximum power. The following are the operating parameters for depositing SnO_2 thin films: Base pressure = 2×10^{-6} mbar, O_2 partial pressure = $4-4.5 \times 10^{-4}$ mbar, deposition rate = 1-1.5 nm/sec, and RF-power = 25 W.

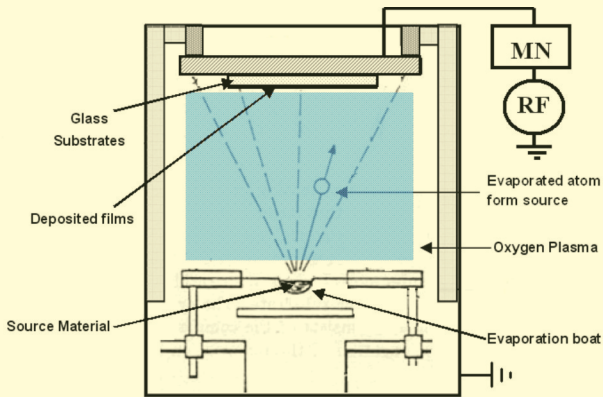


Fig. 2: A schematic diagram of Plasma Assisted Thermal Evaporation for Tin Oxide thin film deposition; where MN and RF are impedance matching network and 13.56 MHz RF supply respectively.

The transmissions of the deposited films in the visible–infrared (VIS-IR) region are measured using the spectrometer consisting of a 1/8 m monochromator, a silicon-photo detector and a dual phase lock-in amplifier. The crystallinity of the films was investigated by XRD (Rich Seifert & Co., Germany) using Cu-K α radiation, whereas SEM (LEO, UK) was used to study the surface morphology and thickness of films (cross-section). The resistivity of the films was measured at room temperature by Four-probe method using a Keithley source meter (2400-C).

3. RESULTS AND DISCUSSION

Figure 3 shows the optical transmission spectra, in the range of 350 to 1000 nm, of SnO₂ thin film deposited by PATE. It is observed that the optical transmission of SnO₂ films have an average transmittance of ~80-90%, confirming the high transparency in this range. Further, the films grown at substrate temperature 350°C have higher transmission than the films deposited at 250 °C, emphasizing the role of substrate heating during deposition.

XRD pattern of the SnO₂ thin film deposited at 350 °C is shown in Figure 4. The film deposited at 250°C is nearly amorphous in nature, whereas the increase of substrate temperature to 350°C caused the crystallization of the film,

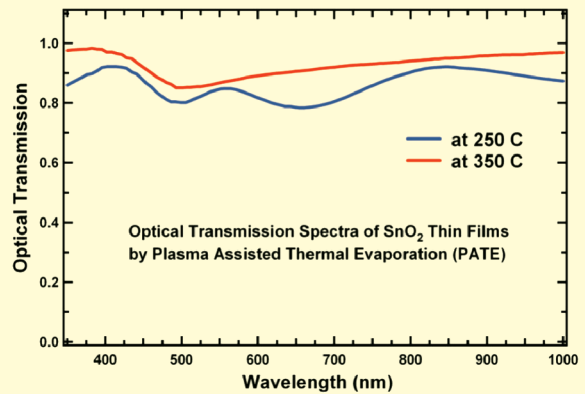


Fig. 3: Optical transmission spectra of SnO₂ thin films deposited on glass substrates by PATE at temperature 250°C and 350°C

which is also noticed by other researchers [14]. The films deposited by PATE at 350°C show three main peaks namely SnO (002), SnO₂ (101) and SnO (111). Hence, it is evident from XRD that the films prepared by PATE have SnO and SnO₂ phases, and confirm the presence of mixed phases in the deposited films. Since the XRD peaks are sharp, it is clear that the film deposited at substrate temperature 350°C by this technique is polycrystalline in nature.

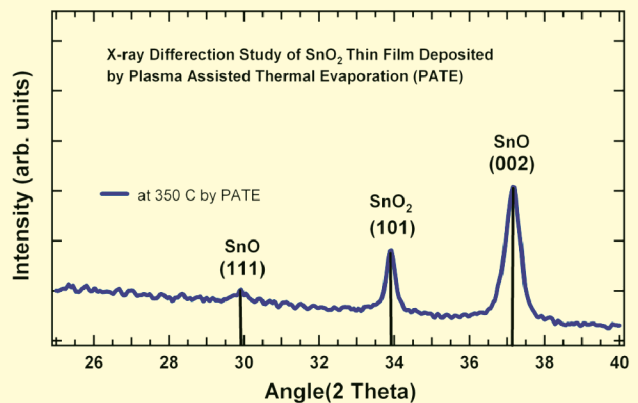


Fig. 4: XRD patterns of SnO₂ films deposited by PATE on glass substrates at 350°C.

SEM image (Fig 5) shows that the film prepared by PATE technique is continuous and pinhole free. As seen in SEM monograph, deposited film has characteristic needle shaped grains, also reported for doped SnO₂ thin film [15].

The electrical resistivity of SnO₂ films was measured at room temperature using Four-probe technique; and the results show that all the deposited films are conducting in nature. The electrical resistivity of films deposited by PATE was observed to be in the range of $2-6 \times 10^{-4} \Omega\text{-cm}$.

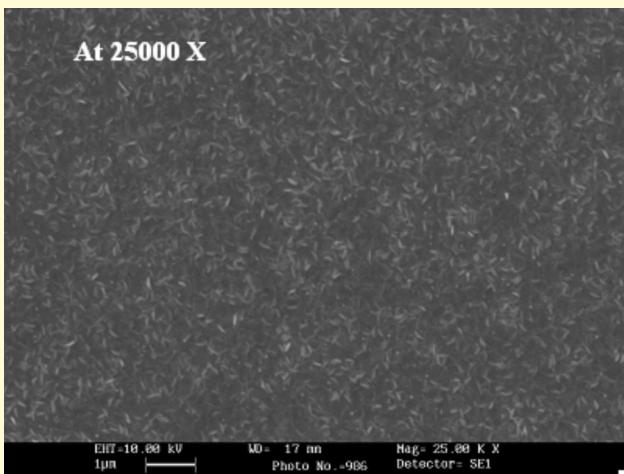


Fig. 5: SEM monographs of SnO₂ thin film deposited at a substrate temperature 350°C by PATE techniques with 25000X magnification.

4. CONCLUSION

The optical, structural and electrical properties of SnO₂ films deposited by PATE are investigated for the substrate temperature in the range of 250-350° C. An average transmittance of ~80-90% and electrical resistivity $2-6 \times 10^{-4} \Omega\text{-cm}$ were obtained for SnO₂ films deposited on glass by PATE. XRD results confirmed that the films prepared at 350° C possess crystallinity, and the absence of un-reacted Sn in the films shows the importance of plasma based process. Surface morphology revealed by SEM shows needle shaped grains present in the films deposited by PATE. Hence, higher transmission and lower electric resistivity of SnO₂ films obtained by PATE process makes this material useful for application in optoelectronics devices.

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Emission Analysis of the Plasma Pyrolysis System installed at GCRI, Ahmedabad

Dr. S. K. Nema



FCIPT, Institute for Plasma Research, has developed the plasma pyrolysis technology to destroy medical waste, consisting mostly plastics and cotton. Plasma Pyrolysis is a destructive decomposition process. In this process the waste is exposed to high temperatures in oxygen starved environment. High temperature is produced by a plasma torch, which converts electrical energy into heat energy. The pyrolysis

results in main chain scission and generation of free radicals, which efficiently break C-C bonds and C-H bonds present in plastic and cotton molecules. This process occurs at higher than 650°C in the primary chamber. These combustible gases flow through a secondary chamber, by means of an induced draft fan, where air is mixed with these gases for combustion. The temperature of the secondary chamber goes up to 1000°C. The residence time of these gases in the secondary chamber is around 1sec, which is sufficient to break the dioxins and furans, if they are formed in the primary chamber because of the presence of material like PVC etc in the waste. The flue gases after secondary chamber, reach the scrubber unit where the temperature of the hot gases is reduced to 70°C. The relatively cool gas is then thrown in atmosphere by means of an ID fan and chimney. The required height of the chimney in this system is less than 7 meters.

FCIPT has installed and commissioned a prototype plasma pyrolysis system, for disposing plastic and medical waste, at Gujarat Cancer Research Institute (GCRI), Ahmedabad on 26th August 2009. The waste disposal capacity of this system is 20 kg/hour. The photograph of the installed system is shown in figure 1. This development has been funded by Department of Science and Technology, Government of India; under the Technology Demonstration Program. The flue gases, emitting from this system, have been analysed with the help of M/s Vimta Labs, Hyderabad. The gaseous samples have been collected, while disposing the category 6 and category 7 of biomedical waste. It was observed that the quantity of Dioxin and Furan in the flue gases emitted from the system was well under the limits set by Central Pollution Control Board (CPCB). As per the CPCB norms the permissible limit of Dioxin and Furan from the emission stack gas should be less than 0.1 ng/ Nm³, whereas the emission from the system is found to be 0.0039 ng/ Nm³. All other constituent gases in the emissions were also found to be very less than the CPCB norms. The details of the various gas constituents that were measured in the stack gas, their permissible limit as per CPCB norms, and the actual values are described briefly in table 1.



Fig.1: Photograph of the Plasma Pyrolysis System installed at GCRI, Ahmedabad

Table 1: Details of the permissible limits and actual values

Gas constituents	Norms given by CPCB (As per the Gazette of India 26 th June 2008)	Actual Emission in Plasma Pyrolysis system
Oxygen	---	12.0 %
Carbon dioxide	>7%	8.3%
Carbon monoxide	100 mg/Nm ³	538 ppm
Sulphur dioxide	200 mg/Nm ³	90.1 mg/Nm ³
Oxides of Nitrogen	400 mg/Nm ³	259.2 mg/Nm ³
Particulate matter	50 mg/Nm ³	27.1 mg/Nm ³
Chlorine as Hcl	50 mg/Nm ³	29.6 mg/Nm ³
Chlorine as cl2	----	26.1 mg/Nm ³
Dioxins & Furans	0.1 ng/Nm ³	0.0039 ng/Nm ³
Dioxin & furan in Scrubber water	(Norms are not mentioned in The Gazette of India)	0.06 pg/L
Dioxins & furans (Primary Chamber Residue)	(Norms are not mentioned in The Gazette of India)	<0.02 ng/Kg

Conclusions : A prototype plasma pyrolysis system, with a capacity of 20 kg/hour, was installed and commissioned successfully at GCRI, Ahmedabad. The system is meant for destroying medical waste. Experiments were carried out to quantitatively analyze the effluent gases, emitting from the system, while the medical waste was getting pyrolyzed. It was observed that the emissions were well within the limits set by CPCB.

Synthesis of Carbon Nanotubes

Balasubramanian C



Carbon nanotubes (CNT) were first discovered by S. Iijima in 1991 [1] in the soot formed in an arc discharge process between two graphite electrodes. The CNT discovery was preceded by the discovery of Fullerenes in the year 1985 [2]. Fullerenes, also known as buckyballs, consist of C_{60} atoms linked by hexagonal rings (and sometimes by pentagonal or heptagonal rings, though to a lesser extent) to form a hollow sphere. These also form an allotrope of carbon, apart from graphite and diamond. Carbon nanotubes can be considered as belonging to cylindrical fullerene structure.

The carbon nanotube can be thought of as forming from atomic layers of hexagonally linked carbon atoms (graphene sheets). Single or multiple layers of graphene sheets can be thought of as rolling to form seamless cylinders resulting in a single wall carbon nanotube (SWCNT) or a multiwall carbon nanotube (MWCNT). Single wall carbon nanotubes have diameter between 1 and 3nm, whereas the diameter of the multiwall carbon nanotubes ranges even upto few tens of nanometers. The ratio of diameter to the length of the nanotube is given by the aspect ratio, and is a crucial parameter effecting many of the properties and applications of the nanostructure. Carbon nanotubes are reported to behave either as insulator, semiconductor or metallic depending on the *chirality* of the nanotubes. Depending on the angle the tube axis makes with the normal, three types of chirality are possible: *Arm chair* type; *Zig-zag* type and *Chiral* tubule. The properties of a nanotube could vary depending on the chirality.

Subsequent to the initial discovery of carbon nanotubes by Iijima [1] using the arc discharge method, more refinements were carried out by various researchers to improve upon the yield, quality and structure of the nanotube. In 1992 Ebbesen and Ajayan reported the bulk synthesis of nanotubes from graphite cathode by arcing in inert atmosphere [3]. Presently there are diverse

techniques employed for CNT synthesis, like pyrolysis of hydrocarbons over catalysts [4,5], laser vapourization of graphite [6,7], electrolysis of ionic salts using graphite electrodes [8,9], thermal CVD, HFCVD [10], PECVD [11], thermal plasma jet [12] etc. The products exhibit different degrees of crystallinity and morphologies like straight, curled, branched, spiral, helix shaped *etc.*

Synthesis of the nanotubes could also involve use of transition metal catalyst like Ni, Co, Fe. The nanotubes can also be grown on patterned substrates that could result in vertically well aligned nanostructures.

Arc plasma and laser ablation processes are used for producing CNT in bulk quantity. However these processes, to a certain degree, suffer from the presence of high levels of amorphous carbon. Thermal CVD process does ameliorate this drawback at the cost of reduced robustness of the CNT produced.

At FCIPT, we have successfully synthesised CNTs by arc discharge process. An arc was struck between two graphite rod electrodes by applying a DC current of 100 A and voltage of approximately 30-40 V. The diameter of the anode graphite electrode was kept slightly larger than the cathode graphite rod to ensure a stable arc presence during the synthesis process. It is also preferred to carry out the arcing in helium or any inert atmosphere as this prevents burning of graphite in air and also helps in faster heat dissipation. The arcing was done for duration of approximately 3 minutes.

Carbon nanotubes are formed on the cathode material and appear, macroscopically as soft dark grey material on the graphite rod. This part of the graphite was observed under the Scanning Electron Microscope (SEM). Figures 1 & 2, below, show the images recorded from SEM. The nanotubes are found to have diameter varying between 20 – 45 nm and length in excess of 5 microns. From an SEM image it is impossible to verify if the product formed is a nanotube or a nanofiber. Transmission Electron Microscopy is the best technique to confirm the tubular nature of the product. Figures 3 & 4, below, show the TEM images of the nanotubes produced using a similar experimental setup and with same operating parameters. The product being multiwall CNT one can observe the walls distinctly.

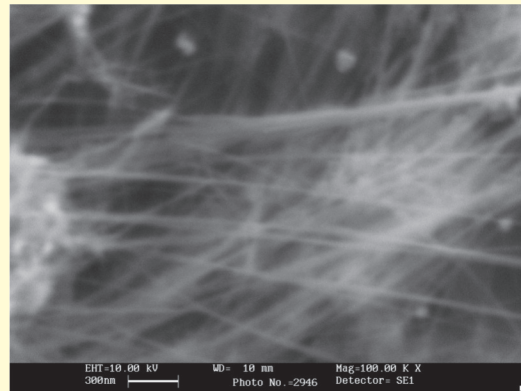
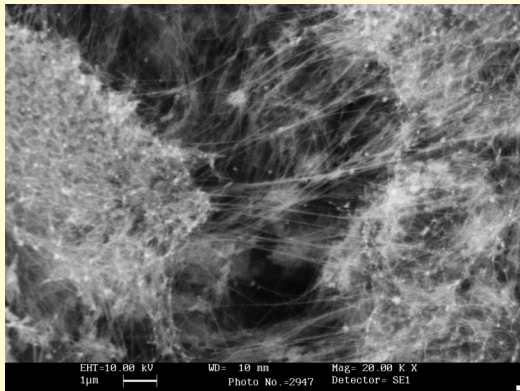
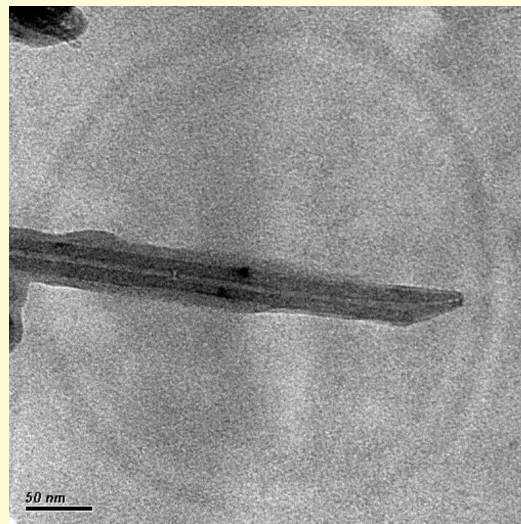
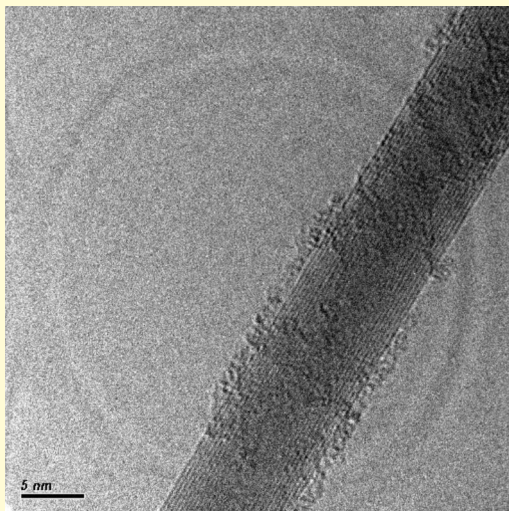


Fig. 1 & 2: SEM images of Carbon nanotube – broader view and enlarged view respectively



Figs 3 & 4: TEM images of CNT prepared elsewhere, using a similar experimental setup and same operating conditions

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Other News

Inauguration of the FCIPT new building

FCIPT has recently celebrated the inauguration of its new building, on 25th August 2010. The inaugural ribbon cutting was performed by Shri Prof. P. K. Kaw, Director, Institute for Plasma Research (IPR). The occasion was also graced by other distinguished guests like Prof. Sen, Dean, IPR; Prof. P. I. John, Chairman, Governing Council, FCIPT etc.



Agreement between LPSC, ISRO and IPR

Indian Space Research Organization (ISRO) has a vision for using plasma-based thrusters for their future space missions. At Liquid Propulsion Systems Centre (LPSC), a unit of ISRO, work has been going on development of plasma based thrusters. With an objective of utilizing the expertise available at IPR, in the field of Plasma Physics and Technology; an agreement was mooted between both the institutes to form collaboration in the field of plasma thrusters and develop a long term facility for thruster plasma study at IPR. The first step was an invitation to IPR scientists to participate in the experiments on the thrust stand at LPSC. A team from IPR went to LPSC and

participated in the experiments. It indulged in discussions and brainstorming sessions with scientists and engineers at LPSC working on this program and suggested various reasons which could be attributed to the thruster quenching. Measurements, which needed to be done for better understanding of the thrusters operation, were also suggested.

LPSC felt that a plasma physics course for engineers and scientists working on this program would be very helpful in understanding the practical problems faced during thruster operation and taking the program forward. The course desired by LPSC and designed by team of experts at IPR is on plasma physics applied to electric propulsion systems involving the following broad areas: (i) Basic plasma physics - single particle motion, drifts, concept of magnetic mirror, confinement and optimization of magnetic field for optimum thruster performance, plasma fluid theory, waves, transport and instabilities, (ii) Experimental aspects – methods of plasma production, plasma sheath, design of plasma thrusters, hollow cathode operation for generation of electrons, plasma interaction with materials such as metals and dielectrics used in thrusters and their effect on thruster operation and lifetime, electric & magnetic diagnostics, advanced diagnostic techniques including infrared thermography, laser induced fluorescence and optical emission spectroscopy, EMI effects (iii) Simulation – numerical modelling of plasmas, 1D, 2D and transient modelling of thrusters phenomena. Hands-on experiments on plasma diagnostics will also be conducted during the course. Course material will be shared by faculties before the commencement of the course and participants will make presentations on selected topics. During the course, popular lectures will be delivered by eminent scientists working in the area of plasma science.

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