

PLASMA



PROCESSING UPDATE

A newsletter from the

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

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Editor's Note

Titania is a naturally occurring oxide of Titanium and finds wide range of applications including in the areas of pigments, cosmetics, food colouring etc. Titania, in the form of nano-powders, has got even more interesting applications. Particularly, the Anatase phase of Titania is used mainly as a photocatalyst under UV irradiation; and this photocatalyst activity is observed to increase immensely when used in nano-size. At FCIPT, nano-titania was synthesized using thermal plasma route. The size of the produced powder was ranging from 7 nm to 60 nm, and ~85% of it is lying in the size range of 16-40 nm. Further, these nano-titania particles were studied for their self-cleaning properties by spray coating them on to cotton fabrics, and deliberately staining these fabrics with Tea, Coffee and Turmeric. The results are encouraging and the details are presented by Dr. C. Balasubramanian.

'Pulsed under-water streamer corona discharge' is an emerging technique that could be used for the destruction of micro-organisms in drinking water, sewage effluents, and also for the degradation of toxic pollutants. Such techniques, based on electric discharges, could be highly efficient in killing microorganism as compared to conventional methods. However, much study was not carried out on the plasmachemical processes associated with the above technique. Dr. -Ing. Suryakant B. Gupta, from FCIPT, has worked in this area and has explained about the streamer initiation and propagation mechanisms in detail, in the article presented in the current issue.

Editor : Alphonsa Joseph

Co-editor : A. Satyaprasad

Conference Presentations from FCIPT

Name of the Author	Topic	Date	Place	Conference
Mr. Akshay Vaid	Design & Construction of a Compact Heater for Vacuum Heat Treatment Processes	29-31, January 2010	Mumbai, Maharashtra	Heat Treat Show-2010
Ms. J. Alphonsa	Plasma Nitrocarburizing process for corrosion resistance of valves used in steam turbines	29-31, January 2010	Mumbai, Maharashtra	Heat Treat Show-2010
Mr. Chetan Jariwala	Thin Film Processing by Plasma Techniques for Photo-voltaic Applications	22-26, February 2010	Surat, Gujara	AICT sponsored Staff Development Program on "Optics and Photons"
Dr. S. Mukherjee	Plasma Technologies at Institute for Plasma Research	12-13, March 2010	Pune, Maharashtra	India and Germany: strategic partners in innovation

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>

RESEARCH AT FCIPT

Nanotitania synthesis and its application in self cleaning of cotton fabric

Balasubramanian C

(This work was part of a M. Tech project carried out by Ms. Dhvani Mewan at FCIPT under the National Fusion Program)

Introduction



Among the various nanomaterials that have attracted wide attention from the application point of view, titanium dioxide (TiO_2) is a prominent one. Titania, even in its bulk form, is frequently used in the production of paints, paper, plastics, cosmetics, food colouring agent etc.

Titania exists in different mineral forms - anatase, rutile and brookite. Anatase type TiO_2 has a crystalline structure that corresponds to the tetragonal system (with dipyrimal habit) and is used mainly as a photocatalyst under UV irradiation. Rutile type TiO_2 also has a tetragonal crystal structure but with prismatic habit. This type of titania is mainly used as whitening agent/ pigment in paints. Brookite type TiO_2 has an orthorhombic crystalline structure. There is another type of TiO_2 , which exist as a monoclinic mineral and is relatively lesser known and used.

Titania is the most commonly used semiconductor photocatalyst. Activated by UV-A irradiation, its photocatalytic properties have been utilized in various applications. This photocatalytic property is greatly enhanced when used in the nanosize. Nanotitania coated fabrics, tiles etc. are already in the market, and nanotitania gives the functional edge to the product - acting as a self cleaning agent in the presence of UV-A radiation. The UV component, present in the sunlight, is sufficient enough to carry out the photocatalytic activity and clean the stained surfaces.

Many methods have been reported for the production of TiO_2 nano-powders, such as sol-gel preparation [1], Microemulsion method [2], Colloidal synthesis [3], Thermal plasma torch [4], Chemical vapour decomposition [5-7] etc.

Experimental

At FCIPT, nanotitania was prepared by thermal plasma processing in air ambient at atmospheric pressure. An electric



arc was struck between two electrodes, both consisting of titanium rod/blocks, with the help of a high current DC power source. The applied voltage was varying (depending on the distance between the electrodes) between 25–32 V, and the arc current was 80 A. The high thermal energy content in the arc plasma melts the anode material (titanium) and evaporates it. In the arc column the titanium is in the ionised state and as it moves away from the arc zone the temperature falls and neutral titanium atoms form, which in turn react with the oxygen present in air ambient to form molecules of titania. Clusters of titania molecules form and this clustering and particle formation continues till sufficient energy exists for such action. In our process, this energy availability is drastically reduced by cooling the reaction chamber so the cluster formation is arrested when the particle size reaches nano dimension. These particles condense on the inner walls of the reactor chamber (substrates can also be placed inside the chamber on which deposition could take place), and these powder particles, in the form of powder, are then collected for analysis. The particles were analysed for their phase and morphology.

The nanoparticles of titania were then ultrasonic spray coated on cotton fabric for different concentrations of the nanotitania. The nanotitania coated fabric was stained by drops of coffee, tea and turmeric. The stained fabric was then placed under sunlight and UV-A light source separately for extended period of time and its decolouration with time was recorded using a camera. The results are given below.

Analysis

The nanotitania powder collected and analyzed using various characterization techniques to ascertain its morphology and composition etc.

The powder was subjected XRD analysis and the spectra clearly indicate the titania product to be crystalline in nature, with prominent diffraction peaks occurring at 25.28°, 48°, 54° and 55.04° – all corresponding to Anatase phase. However, the presence of Rutile phase was also observed (peaks at 27.44°, 36.08° and 54.38°), though to a lesser concentration. The average particle size (approximated from the crystallite size) as calculated from the FWHM of the prominent diffraction peaks in XRD, is found to be ~30 nm.

A high resolution Transmission Electron Microscope (TEM) was used to study the morphology of the particles. A pinch of the powder was dispersed in iso-propyl alcohol with the help of an ultrasonicator and then a micro-drop of this sonicated solution was placed on carbon coated copper grid. This was

then studied under TEM. Picture shown in figure 1 is the TEM image of the nanotitania particles. The particles are clearly seen to be spherical in shape and with size ranging from 16–40 nm with a few scattered particles of size as low as 7 nm and some as high as 60 nm. The particle size distribution as seen in figure 2 clearly shows the maximum number of particles to lie in the size range between 16–40 nm.

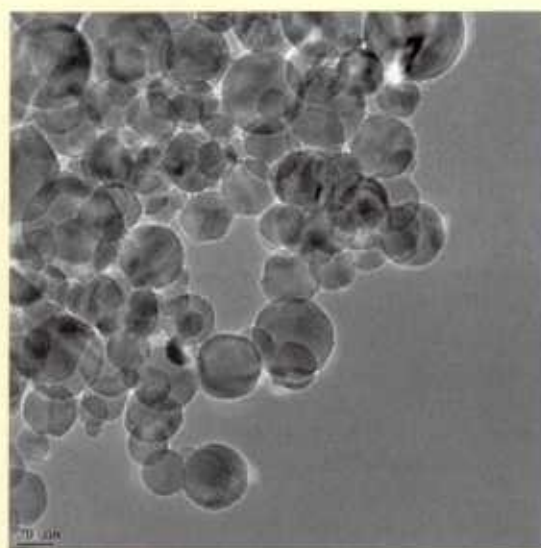


Fig. 1: Transmission electron microscope image of the nanoparticles indicating the spherical shape of the particles.

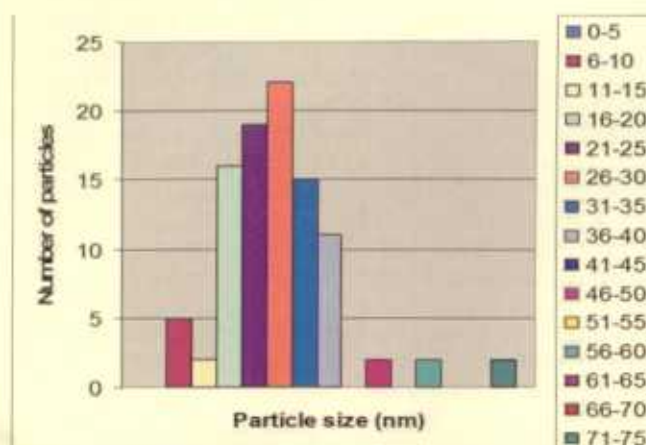


Fig. 2: Particle size distribution, analyzed using the TEM image shown in figure 1.



Self cleaning effect of nanotitania on cotton fabric

These nanotitania particles were coated on cotton fabric pieces, measuring 10 cm10 cm in size, and then these coated fabric were studied for self cleaning property. To carry out these studies, a predetermined quantity of nanotitania powder was dispersed in a 50 ml of iso-propyl alcohol and kept in a ultrasonic bath. This solution, while still being kept in the sonicator, was passed through an ultrasonic nozzle spray and was uniformly sprayed over the fabric material. The fabric samples, after getting dried, were treated to Tea, coffee and turmeric stains (a drop of concentrated solution of tea, coffee and turmeric were placed on the fabric material). The fabric material was then exposed to sunlight and UV-A light source separately. A fabric sample without any nanotitania coating but stained by the above three compounds served as the control sample. This was also tested under sunlight and UV

light separately. The decolouration of the stains over various intervals of time was recorded with the help of a camera. The experiments were performed for three different weight percentages of the nanotitania viz. 0.5 mg/m²; 1.0 mg/m² and 1.5 mg/m². The results of this study are shown in figures below.

As can be seen in figures 3, 4 and 5, the coffee and turmeric stains disappear within 4 hrs when kept under sunlight, whereas the same decolouration occurs in less than 2 hrs when exposed to UV light. The control sample did not show any decolouration indicating that the observed decolouration is purely due to the presence of nanotitania. The stain due to tea, however, did not show much response either under UV or sunlight exposure. It is found that the maximum decolouration occurs for fabric samples coated with 1.0 mg/m² weight percentage of nanotitania.

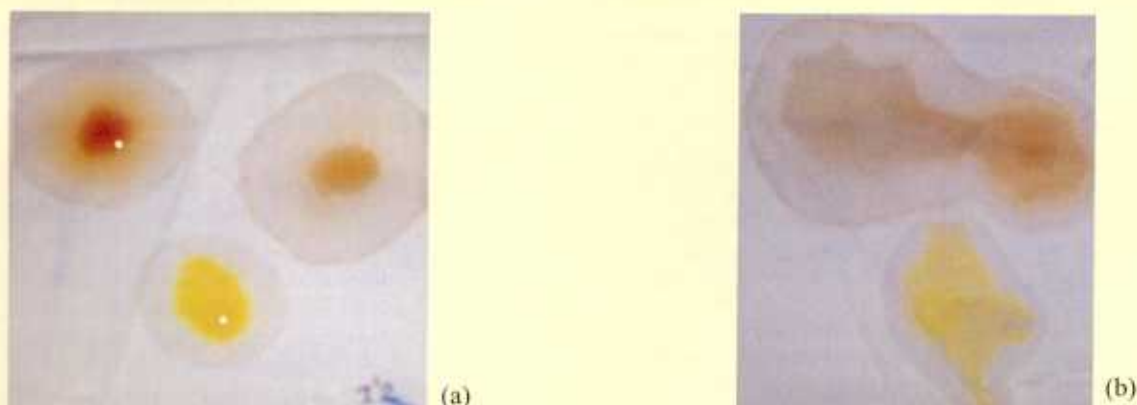


Fig. 3: Virgin cotton fabric sample with stains - top left is tea stain; top right is coffee stain and bottom yellow is turmeric stain (a) before exposure and (b) after exposure to UV over a period of 1 hr (no change was recorded even after 8 hrs exposure).

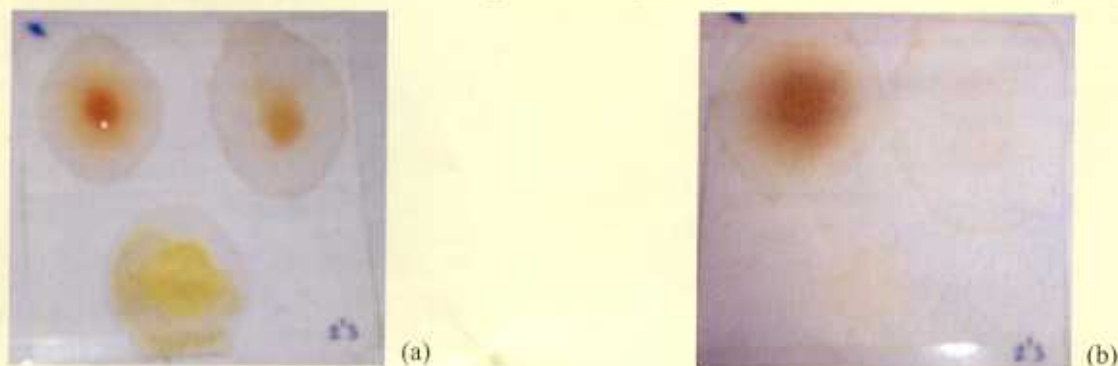


Fig. 4: Fabric sample coated with Nanotitania (concentration 1 gm per m²). Top left is tea stain; top right is coffee stain and bottom yellow is turmeric stain (a) before exposure and (b) after exposure under UV for 2 hrs.

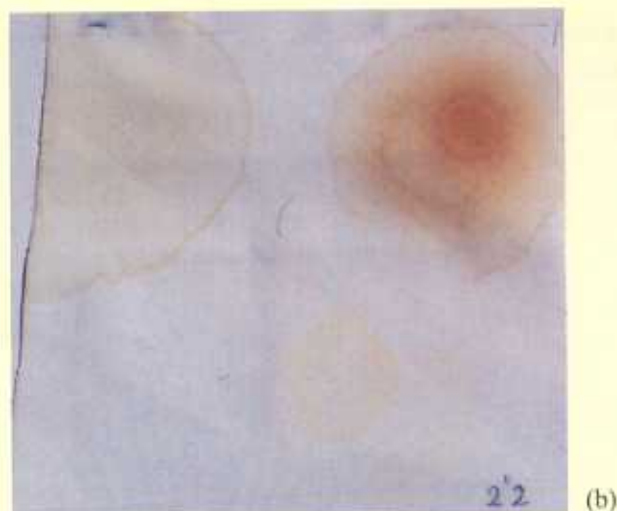
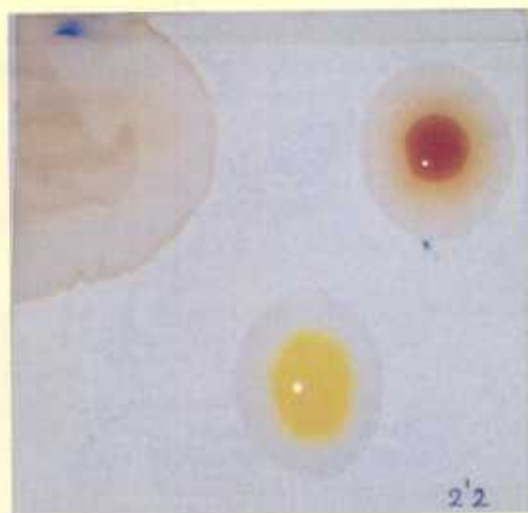


Fig. 5: Fabric sample coated with Nanotitania (concentration 1 gm per m²). Top left is coffee stain; top right is tea stain and bottom yellow is turmeric stain (a) before exposure and (b) after exposure under sunlight for 4 hrs.

Conclusions

Nano sized titania particles were synthesised using thermal arc plasma. These particles were found to be spherical in shape with an average size of approximately 25-30 nm. These particles were found to be highly crystalline with Anatase being the predominant phase.

The tests conducted to study the self cleaning ability of nanotitania coated fabric samples gave positive results in respect of turmeric and coffee stains when exposed to UV source as well as sunlight. The exposure time needed for decolouration under sunlight and UV was 6 hours and 4 hours respectively.

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EMERGING TECHNOLOGIES

Streamer propagation mechanism and its possible applications in pulsed underwater corona discharges

Dr. -Ing. Suryakant B. Gupta is a senior pulsed power engineer at FCIPT



Pulsed electric discharge technology is an emerging technique for the destruction of micro-organisms in drinking water, sewage effluents, and also for the degradation of toxic pollutants. The electric discharge treatment of liquids can be highly efficient with respect to microbial killing and as effective as conventional chemical methods and UV irradiation. In addition, the technology is environmental friendly as it does not involve the introduction of chemicals into the liquids, as is the case with chlorination, which can lead to the formation of carcinogenic and/or mutagenic disinfection by-products. Generally, plasma and plasmochemical processes accompanying electric discharges

in water have received little study to date. Among the different means of electric discharges, a novel method of **pulsed underwater streamer corona discharge** has some advantages over the existing methods used at present. This article explains the streamer formation and propagation process in water.

Streamer discharges: When a sufficiently high electric field is applied to a metallic electrode, streamer channels originate from its surface. These streamer channels are of gaseous nature and electron avalanches can occur in their interior, creating conductive plasma that transports the electrode potential towards the streamer tip. If the electric field at the streamer tip becomes sufficiently strong, field induced ionisation and dissociation enhances the conductivity in front of the streamer head and the streamer begins to self-propagate until the voltage drop inside the streamer channel reduces the electric field at the tip below a critical value.

Depending on the polarity we distinguish between negative or positive streamers originating from the cathode and anode respectively. In water positive filamentary streamers are easier to create. One possibility to restrict the streamer length and to prevent arcing is to limit the duration of the driving voltage pulse. An important consequence of the brief pulse duration is that it minimizes energy dissipation due to ohmic losses in the conductive water.

Specifics of underwater pulsed corona discharges: Various configurations for the initiation of corona discharges in water have been described in the literature. A selection of these configurations has been reproduced in Fig. 1. For basic studies on streamer properties point-plane geometries (Fig. 1-A) are well suited. In these set-ups a thin sharp needle is applied as one electrode and a plate or disk as the counter electrode. In general both electrodes are submerged into the liquid. In some cases a hypodermic needle has been utilized instead of a solid pin and gas was bubbled through it. The point plane geometry is inappropriate for industrial applications because only very restricted volumes can be treated and the lifetime of the needle is rather limited.

A variant of the point-plane geometry is depicted in Fig. 1B. Here the needle electrode is located in the gas plenum above the water while the plate electrode sits in the water. The corona discharge originates in the gas. Oxidants that may have been created in the gas phase must migrate into the liquid to become effective. In the hybrid configuration of Fig. 1C, streamers result both in the liquid phase and in the gas phase. Here the ground electrode is placed at the interface between

gas and liquid and the needles in the gas and in the water may be supplied from the same pulse generator although care must be taken not to create an arc discharge in the gas plenum.

A different type of reactor is based on a diaphragm discharge (Fig. 1D). In this configuration the HV electrodes are separated by an insulating disk, which is made from quartz or alumina containing a pinhole of a few μm diameters in its centre. When a high voltage pulse is applied to the electrodes, due to the ionic conductivity of the water, polarization occurs across the diaphragm, and the applied voltage drops across it leading to strong electric fields in the pinhole and finally to the development of a streamer.

To overcome the deficiencies of the configurations described above we have selected the set-up presented in Fig. 1E for our investigations. Here hundreds of streamers are created simultaneously from an anode covered by a porous ceramic layer. The oxidants as well as the other physical effects are produced inside the water and react simultaneously. The system seems scalable to large throughputs and the electrodes have the potential to operate for long time without maintenance. As indicated in Fig. 1F a large fraction of the reactor volume comes into direct contact with the effects resulting from the streamers.

Streamer model: In the streamer channel only free electrons gain energy and since the equilibration time is much longer than the active lifetime of the channel ions and neutrals remain cold. Therefore a non-equilibrium plasma is established inside the streamer channels. Electron collisions with water molecules are considered to be the main source of oxidant production inside the channels. However the details of streamer initiation and propagation in water and the concurrent and subsequent formation of active chemical species are currently not completely understood. In the following sections we summarize our present knowledge on streamer initiation and propagation in water. Initiation from metallic as well as ceramic surfaces is considered.

Primary Streamers: If the electric field at a metallic tip exceeds a certain threshold value a tree-like filamentary structure is observed. This structure is called the primary streamer. Its filaments are characterized by a very weak light emission and a negligible conductivity. They do not disturb the initial electric field configuration. The symmetry and size of this primary streamer are largely determined by the field distribution at the anode tip. High resolution images suggest that they consist of small bubbles. It is believed that these bubbles can form in the water due to field induced phase instabilities.

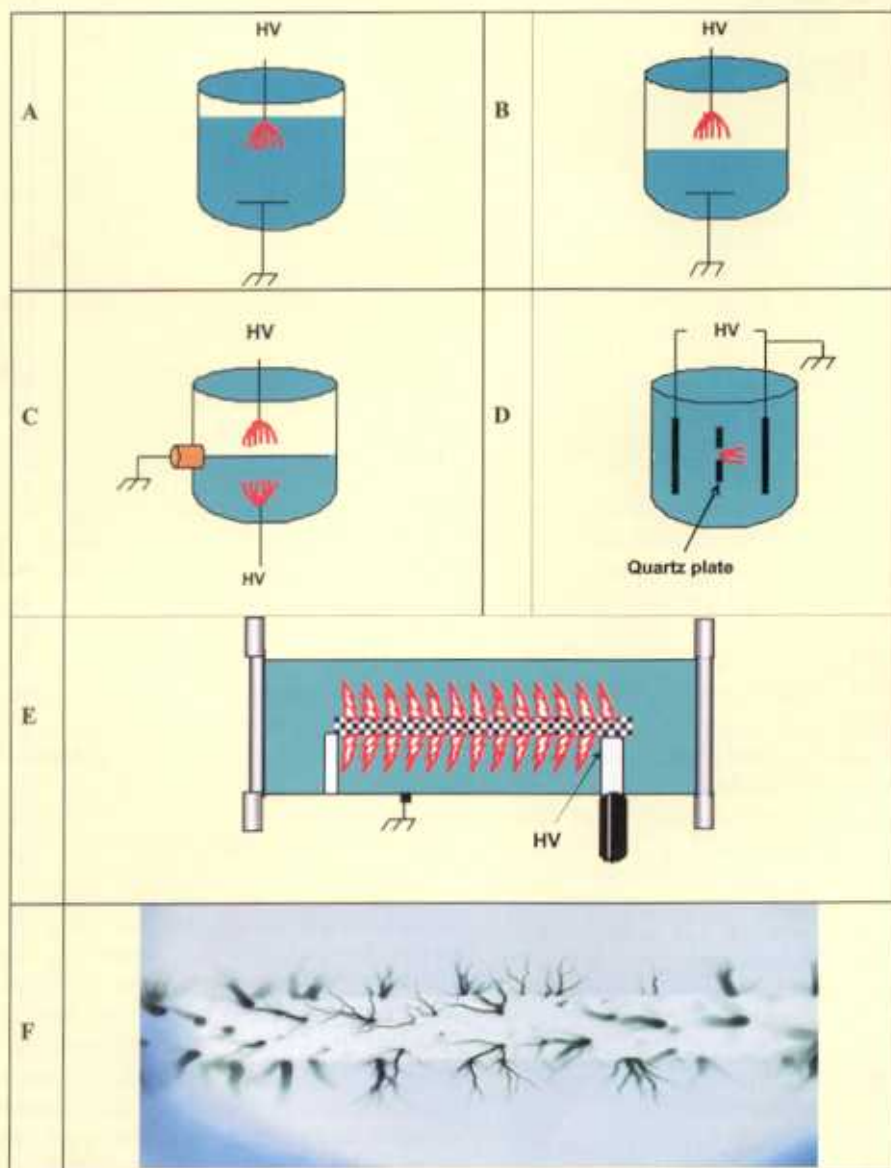


Fig. 1: Different configurations for the initiation of streamer discharges in water. [A] Point-plane geometry for liquid phase corona discharges. [B] Point-plane geometry for glow discharge initiation in the gas plenum above the water. [C] Hybrid geometry for simultaneous streamer discharge initiation in the water and in the gas plenum. [D] Streamer discharge originating from a diaphragm. [E] Coaxial pulsed underwater corona reactor with anode covered by a porous ceramic layer. [F] Inverted photographs of axially distributed underwater corona discharge channels.

Secondary streamers: As time progresses the primary streamer filaments expand and the density inside the channels reduces. At some point the conditions for electron avalanche formation are reached. This appears first at the foot (i.e. base) where the field strength is highest and the density is lowest and then propagates in one of the filamentary channels offering the most favourable conditions towards the rim of the primary streamer. Electron avalanching in the channel increases the conductivity and transports the potential of the metallic tip to the head of the channel. In general this is accompanied by a strong field enhancement establishing conditions for the initiation of a self-propagating secondary streamer.

Streamer initiation from a porous ceramic layer: Macroscopic electric fields above 1 MV/cm are needed to initiate a primary streamer in water, which is the less stringent pre-condition for secondary streamer formation and propagation. Manageable voltages can reasonably realize such high field strengths only by using field enhancement effects at point tips, thin wires, or across a thin layer of porous dielectric material. At spherical point tips the electric field

strength E is proportional to U/r_c (here U is the applied voltage, and r_c is the radius of the wire tip). It has already been pointed out that sharp needles cannot be used for industrial water processing because of limitations in the needle erosion and in the treatable volume. A more suitable solution seems to launch the streamers from an anode, coated with a thin layer of porous ceramic.

For pulse duration τ shorter than the dielectric relaxation time $\epsilon_r \epsilon_0 / \sigma$, water behaves like a dielectric but for $\tau \gg \epsilon_r \epsilon_0 / \sigma$, it can be considered as a resistive medium. The permittivity of water is 81 while it becomes 8 to 10 for ceramic. The conductivity of porous ceramic is determined by the geometry and the number of water filled pores connecting the metallic anode surface with the bulk water. Since this conductivity can be kept small we obtain a field enhancement in both time domains considered above.

However, for the ceramic layers the field enhancement due to resistive voltage division between the water and the ceramic was much larger. An equivalent circuit of the coaxial reactor with an anode covered by a thin ceramic layer is presented in

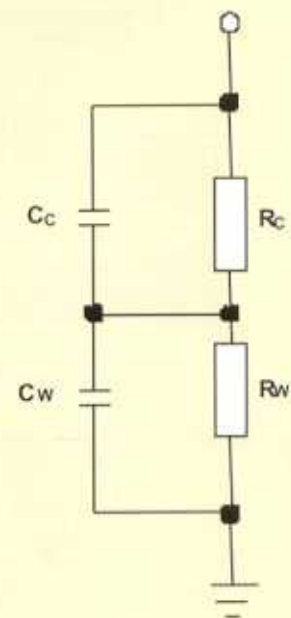
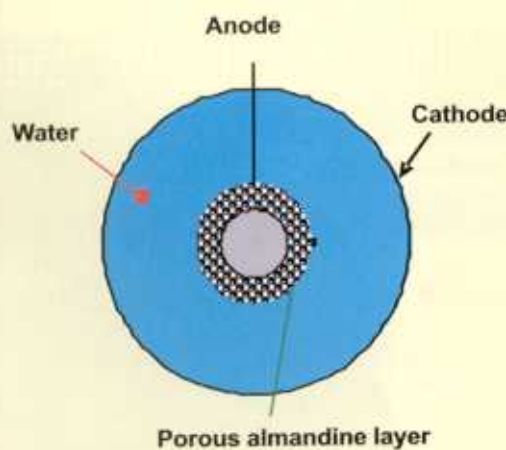


Fig. 2: Cross sectional cut through a coaxial pulsed underwater corona reactor and corresponding equivalent circuit. (R_c = resistance of porous ceramic coating, R_w = resistance of conducting water layer, C_c = capacitance of ceramic coating, C_w = capacitance of water layer).



Fig. 2. Due to this field enhancement a much lower voltage than for the bare anode case is required to initiate a streamer discharge. A pictorial representation of streamer initiation from an anode coated with a porous ceramic layer is shown in Fig. 3. The enhancement of the electric field due to the differences in permittivity and resistivity are given by the following expressions:

(A) Effect of differences in permittivity:

where $E_{c1} = \left[\frac{\epsilon_w}{\epsilon_c} \right] E_a = 10E_a$
 E_{c1} = Electric field at the ceramic surface
 ϵ_w = Permittivity of water ~81
 ϵ_c = Permittivity of ceramic ~8-10
 E_a = Electric field at the anode surface without coating

Secondary streamer (from ceramic layer): Secondary streamer propagation does only occur if the electric field at the tip is sufficient to initiate a local micro-discharge in the water. It has been concluded from measurements of the channel diameter at the tip that field strengths much above 20 MV/cm appear in the water in front of the streamer head. Such field strengths are sufficient to create field induced dissociation (into OH⁻ and H⁺) and ionisation of water molecules increasing the water conductivity by several orders of magnitude. It is well known that both the dissociation and the ionization of water molecules increase exponentially with the applied electric field. The subsequent current flow charges the new segment, heats the water instantaneously and launches a strong shock wave into the water. The analysis of

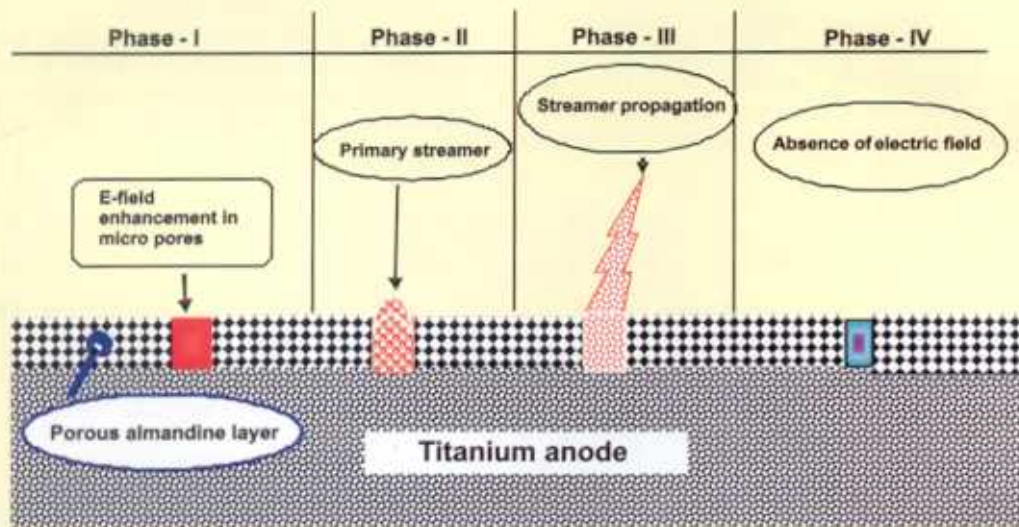


Fig. 3: Model of streamer initiation from micro pores in the ceramic coating.

(B) Influence of differences in resistivity:

where $E_{c2} = \left[\frac{V_a R_c}{d(R_w + R_c)} \right]$
 E_{c2} = Electric field at the ceramic surface
 R_w = Resistance of water layer
 R_c = Resistance of porous ceramic coating
 d = Thickness of ceramic coating
 V_a = Anode voltage
 V_c = Voltage across ceramic coating

R_c is mainly determined by the porosity of the ceramic layer and the conductivity of the water filling the pores.

shock waves resulting from the streamer discharge channel strongly supports the conclusion that the initial electric breakdown occurs in the high-density water. The new section becomes part of the streamer channel after expansion and complete polarisation. Secondary streamers advance with a velocity of 30 km/s. Their advancement stops if the voltage drop along the streamer reduces the effective voltage at the streamer tip below the inception voltage required for self-propagation.

Shock wave analysis demonstrates that during streamer propagation a very short (2-3 ns) pressure pulse of 2-3 GPa

amplitude expands into the surrounding water. The initial streamer radius is estimated to be less than 4 μm . The propagation velocity of streamers was found to be constant over a wide voltage range while the number of streamer branches increased with voltage. The measured electron density at the streamer tip is of the order of 1.5×10^{17} per cm^3 . It reduces to less than $10^{16}/\text{cm}^3$ at the streamer foot. From spectroscopic data molecular rotational temperatures of $T_{\text{rot}} = 5000^\circ \text{K}$ have been inferred. Since much lower vibrational temperatures were obtained it was concluded that the streamer plasma was not in equilibrium. It was also observed that at lower water conductivity the streamer growth occurred in steps. During each streamer growth step a current pulse was recorded co-related with intense light emission. Between pulses an intermission was observed whose duration depended upon the conductivity of the liquid. The fact that the streamer channels became visible only during current flow indicated that the channel plasma remained cold and resistive. Only during the active phase of streamer advancement the plasma inside the channel is heated by the polarization current. At higher water conductivity a continuous ion flux through the streamer surface contributed to the current inside the channel which kept the channel plasma hot and sufficiently conductive.

In a pulsed underwater corona discharge propagating plasma channels (also termed streamers) are created. Electrons present in the plasma channels can dissociate water molecules and produce various reactive radicals ($\cdot\text{OH}$, $\text{H}\cdot$, $\text{O}\cdot$, and $\text{HO}_2\cdot$) and molecular species such as

H_2O_2 , H_2 & O_3 , as well. As shown in Fig.4, apart from these chemical oxidants, solvated electrons, UV-radiation, and strong electric fields at the streamer tip appear. In addition, expansion of the plasma channel against the surrounding water generates intense shock waves, with pressure amplitudes of the order of hundreds of MPa. The resulting shockwaves also help to induce free radical reactions indirectly via electro hydraulic cavitations. It is supposed that a possible synergy between these effects makes pulsed corona discharge treatment of water an efficient disinfection method.

OTHER NEWS

Installation of a magnetron based PVD system at M/s TATA Steel, Jamshedpur

FCIPT has developed and supplied a full-fledged magnetron based plasma PVD system to M/s Tata Steel, Jamshedpur. This activity involved the design and fabrication of the vacuum chamber, procuring the pumping system, the magnetron device and other accessories, integration, testing and demonstration of the system at FCIPT. The deposition chamber is 40 cm in diameter and 40 cm in height, and has a provision for fitting a 3 inch planar magnetron. A project team led by Mr. Ramakrishna Rane, has successfully installed & commissioned the system at M/S Tata Steel, Jamshedpur, in March 2010. The system is basically meant for carrying out

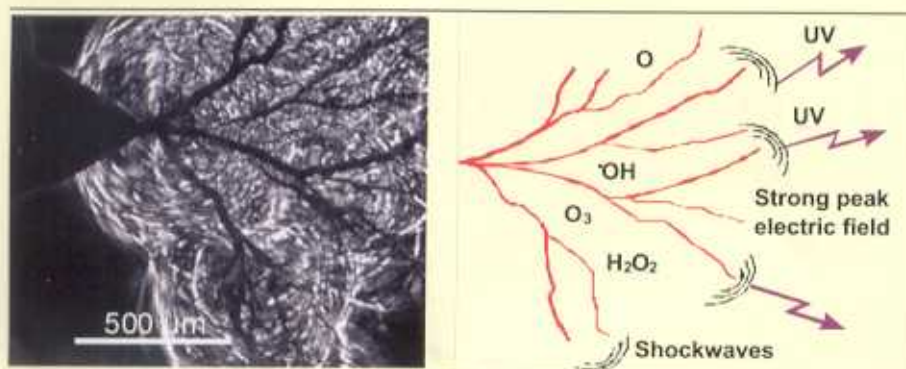


Fig. 4: [A] Shadowgraph of a pulsed underwater streamer discharge from a point electrode, [B] Schematic illustrating different physical effects occurring in the discharge.



R&D activities in metal and alloy coatings. A photograph of the supplied system is shown below.



Photograph of the developed PVD system for TATA Steels, Jamshedpur.

Installation of Atmospheric Pressure Plasma Processing System for Wool Research Association (WRA), Mumbai

FCIPT has developed a dielectric barrier discharge (DBD) based atmospheric pressure plasma processing system to surface treat Merino wool and other such fibers, for WRA, Mumbai; in order to improve its dye uptake efficiency and to make it itch-free. The photograph of the system is shown in figure 1. The system is equipped with a high voltage power supply, and the necessary pumping system (to create the base vacuum). In the developed system, uniform DBD discharge could be generated over an area of 45 X 45 cm², using various

gas combinations. A project team, led by Ms. Nisha Chandwani, has successfully installed & commissioned the system at WRA, Mumbai, in March 2010



Fig. 1: Photograph of the atmospheric pressure plasma processing system, developed for WRA, Mumbai.

Best Poster Award

Under the guidance of Dr. Balasubramanian of FCIPT, IPR, Ms. Dhvani P Mcwan (M. Tech student in Chemical engineering from Nirma University, Ahmedabad) has successfully finished a project on *Synthesis nano Titania using therma plasma route*. The results of the project were presented, in the form of a poster, by Ms. Dhvani at 21st AGM of Materials Research Society of India (MRSI) at Baroda, Gujarat, on 9th February 2010; and this poster has won the best poster award.

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