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Double-Sided High-Frequency Corona Brush Discharge

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Corona Brush Discharge (CBD) represents a new type of a high-frequency corona discharge. One of the principal characteristics of this discharge is that corona occupies a whole volume between a special brush-shaped electrodes in a discharge chamber [1,2,3].

The results of the study of the double-sided high-frequency corona brush discharge (DSCBD) when a new type of Tesla coil is used as a power supply - the three-phase Tesla coil (3PTC) [4], which gives uniform output voltage in each operating pulse - are presented in this paper.

The experimental device shown in Fig. 1 hae five brush-shaped electrodes (BE_1-BE_5) placed sequentially in a glass tube (GT), that is a DSCBD tube. The DSCBD tube is connected to a ventilation system of a capacity up to 150 m^3/h. Inner diameter of GT and brush electrodes is 11 cm, and length of GT is also 11 cm.

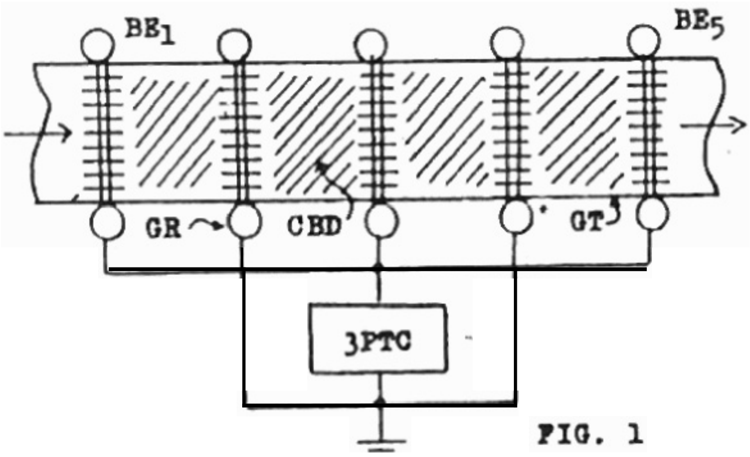
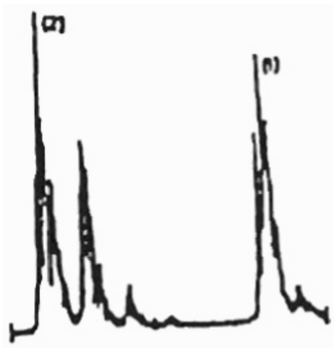


FIG. 1



PIG. 2

Pins of the brush-ehaped electrodes are fastened to the electrode mesh (1 line/cm with element wire of 1 mm in diameter). The guard rings (GR) on the electrodes, with theirs cross-sectional radius greater than a critical one, are used far electrostatic shielding to prevent edge breakdown. The electrodes of such construction does not make a considerable obetacle to a flow of operating gas through them. The electrodes BE_1, BE_3, and BE_5 are connected to one (hot) end of 3PTC, while the electrodes BE_2 and BE_4 are connected to another, grounded end of 3PTC.

, When 3PTC is energized, corona discharge is established and it completely occupies the space between the all electrodes and emits uniform light: from the whole volume of double-sided corona brush discharge (DSCBD). It is to be noted that DSCBD is *very* stable in the whole volume between electrodes. Characteristics of this discharge are similar to those of corona brush discharge described earlier [1,2]. In Pig, 2 is shown a part of the DSCBD spectrum for second positive system of N_2 (337.1 nm (1) and 357.7 nm (2)) for air at atmospheric pressure and voltage of 3PTC U=250 kV at frequency f=200 kHz. With air-watar vapor mixture as operating gas, one gets in discharge nitrogen oxides which with water vapor forms nitric acid.

Pulse corona can be used for abatement of SO_2 and NO_x from flue gases [5]. In DSCBD active corona occupies practically the whole volume of diecharge tube, so that one may expect a great efficiency of this type of discharge in application far flue gas cleaning from SO_2 and NO_x.

Studies with use of larger number of electrodes than five using 3PTC as a *power* supply with various voltages and frequencies are in progress.

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[4] V. I. Miljević, Tesla Coil Builders Association News, 16 (1997) 7.

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imply that the energy source for the perturbation flow is the shear in the comparison flow, and the energy sink is viscous dissipation. In between is a complicated nonlinear energy transfer term, but this term averages to zero over the volume occupied by the fluid. On average, the total energy of the perturbation flow is constant, which implies that energy input and dissipation balance in the long run.

This remarkably simple observation is the key to the whole argument. The mathematical steps in the argument are simply the application of two well known inequalities associated with the names of Cauchy and Poincaré.

Cauchy says that if a function is squared and then integrated (over a region of unit volume), the result is bigger than if it is first integrated and the integral squared. Poincaré says that if a function vanishes at the ends of an interval of length h, then the integral of its square is bounded by $\pi^2 h^2$ times the integral of its derivative squared. These inequalities allow us to take the integral defining the dissipation and construct an upper bound in the form of a completely different-looking integral!

The analytical steps can be performed with any comparison flow. But it turns out that choosing a comparison flow in the form in figure 2b yields a lower upper bound than a comparison flow of the form 2a. Why should this be so? Roughly, the argument is as follows. The dissipation of the true flow consists of three terms: one representing the comparison flow, one representing the perturbation flow, and one representing their interaction. The first can be calculated exactly and the second is easy to treat. The interaction term is, as usual, the nasty one. But the interaction term is non-zero only where the comparison flow has non-zero shear. So for a comparison flow like 2b, the interaction term only comes from the thin layers near the rigid walls. The last step in estimating the interaction term is to observe that since the perturbation flow is exactly zero at the rigid walls, it must be small in these same layers.

The analysis just described must be done carefully, since the magnitude of the shear in the "boundary" layers increases as their thickness decreases. However, it turns out that if the shear layer thickness is chosen properly, then the sum of the second and third terms in the dissipation is guaranteed to be negative. Hence the first term – which is known precisely – gives the upper bound. Doering and Constantin remark that it is perfectly possible that other comparison flows might give even lower upper bounds, but they haven't explored any more. The field is open to anyone who wants to compete! And of course, the technique is applicable to flows in many other geometries.

The contribution of Doering and Ginstantin is three-fold: (a). Their analysis puts the dimensional argument on a firm footing, at least in the case of the present problem. (b) Since 1/(8√2) approximately equals 0.09, the actual dissipation is considerably smaller than might be expected simply from the dimensional estimate. Remember that this result is an upper bound, and the true dissipation is probably even smaller. (c) The techniques used are really elementary in terms of the level of mathematics, although of course very innovative. This type of analysis may well become a valuable tool in the hands of many scientists and engineers.

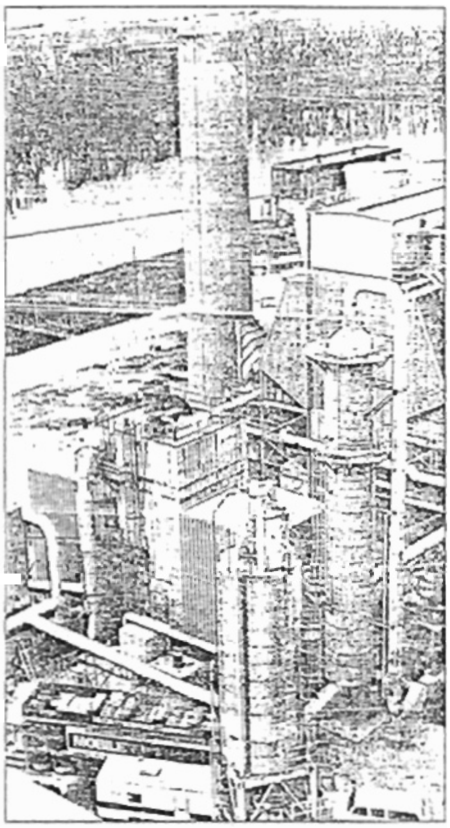
Plasmas join the fight against acid rain

From **Graeme Lister** at Central Research Laboratories (Thorn EMI), Hayes, UK

THE knowledge that scientists in Russia and the US were each developing systems for delivering electron beams with MeV energies using megawatts of power would, until recently, have implied an escalation in the fight for "Star Wars" domination. However, researchers from these two nations, together with others from Japan, Germany and Poland, are planning to use this technology in the war against atmospheric pollution and acid rain. Particularly targeted are the flue gases, including nitrogen oxides (NO_x) and sulphur dioxide (SO_2), which are emitted from countless coal burning stations throughout the world.

The use of "e-beams" for control of atmospheric pollution was one of a number of developing technologies discussed at a NATO workshop on "Non-Thermal Plasma Techniques for Pollution Control" held at Cambridge in September. "Non-thermal" plasmas, as the name implies, are plasmas in which the electron temperatures are considerably higher than those of the components (e.g. atoms, molecules, etc) of the ambient gas. Because electrons are the particles best capable of causing dissociation, this preferential heating of the electrons maximises the dissociation and ionisation of the background gas to form radicals that, in turn, decompose toxic compounds which may be present. Non-thermal plasma techniques are particularly efficient when toxic materials are present in very small concentrations, as is the case for flue gas emissions. In the process, the temperature of the gas or liquid being treated need not be significantly perturbed. This contrasts with the use of thermal plasma arcs for liquid and solid waste disposal ("Plasmas can clean up your backyard" by Mervyn Copsey *Physics World* May 1991 p23). Thermal plasmas typically operate at gas temperatures of a few thousand degrees kelvin and the heat generated by the process provides an efficient means of decomposing large concentrations of hazardous waste.

E-beams can be used to fire high-energy electrons into a large volume of flue gas, producing a cascade of secondary electrons. A very large volume plasma is formed, which can be used to initiate the conversion of SO_2 and NO, contaminants to their



Acid attack – Ebara Environmental's Power and Light Demonstration Unit, Indianapolis which uses electron beam technology to clean up flue

respective acids, and these may then be collected by electrostatic precipitators or bag filters. Alternatively, if ammonia (NH_3) is introduced into the gas, these acids can be converted to ammonium sulphate and ammonium sulphate-nitrate, which may be recovered in powdered form and used as agricultural fertiliser. The first investigations into irradiation of flue gases were by Ebara Corporation in Japan in 1970 and since then the technology has been proven on exhaust gases from small oil- and coal-burning power plants and a coal fire utility plant. A plant to treat ventilation gases from road tunnels will also become operational in Japan during 1992.

E-beam technology has the disadvantages of high capital cost and the need to shield potentially hazardous X-rays which are produced in the process. One possible alternative technology is the corona discharge, a comparatively recent entrant to the field of non-thermal waste treatment ▶

The principle behind the corona discharge is the creation of plasma filaments – small bursts of plasma – generated when a high voltage is applied between a wire filament and a metal plate. High electric fields are created in the heads of these filaments, which produces large numbers of free electrons, as in e-beam reactors.

Results so far have been encouraging, although the gas volumes treated to date have been considerably smaller than those using e-beams. Corona discharges have the potential advantage that fitting costs may be greatly reduced, since they use the same wire–plate electrode configuration as in the electric precipitators used in conventional "wet scrubbers" for flue gas control. If either of these methods is to replace conventional technology, they will need to use less than 3% of the total electrical power of the generator.

One of the major problems for both technologies is "scale-up" for application to modern large power plants. A typical coal burning power plant expels gases at a rate of more than 1000 $m^3 hr^{-1}$ per megawatt of plant power at a gas temperature of 130°C. Results reported by Norman Frank of Ebara Environmental, Greensburg, Pittsburgh, US, indicate that the largest electron beam treatment plant built to date has a capacity to handle gas flows of 50 000 $m^3 hr^{-1}$, while Luigi Civitano of the ENEL Thermal and Nuclear Research Centre, Milan, Italy, has had results from a test rig corona discharge reactor treating 100 $m^3 hr^{-1}$. The magnitude of the problems remaining to be solved is illustrated by the 4 GWe (gigawatts of electrical power) Drax power station in Yorkshire, UK, which expels 7700000 $m^3 hr^{-1}$ of gas into the atmosphere. The UK power generation companies are keeping a watching brief on the new technology. In the meantime, noxious emissions are being minimised by fitting conventional "wet scrubbers" on the National Power's Drax power plant and the 2 GWe PowerGen plant at Ratcliffe. In this process, limestone is converted by the interaction with SO_2 to gypsum, a harmless by-product sold to British Gypsum for production of wallboard. Plans are also well advanced for the introduction of natural gas-fired combined cycle turbine plants from 1993. NO_x emissions are to be reduced by a retrofit programme for all large power plants to introduce low NO_x burners by 1997.

One of the most encouraging aspects of the Cambridge workshop was the participation of scientists from former Eastern Bloc countries, whose research efforts in pollution control in many areas are matching those of the rest of the world. Press reports have recently highlighted the immense environmental problems faced by these countries, but little has appeared on the large investment in solving these problems. E-beam technology has been developed for flue gas treatment in Poland, Russia and the Ukraine, and for water purification from factories in Russia and Latvia. An active research programme using corona discharges for the removal of noxious gases is being conducted in Czechoslovakia.

Non-thermal plasma technology is obviously at a formative stage and the workshop represented one of the first steps to bring the research community together. Legislative pressure and public awareness of environmental problems are likely to provide the drive for new technologies for pollution control in the next few years. A wide variety of non-thermal plasma techniques are currently being investigated to treat such problems as petrol and diesel vehicle exhaust, polluted water and fumes from paint booths. Even the smells from your local kebab house may one day be removed by a plasma reactor, if the technology can be developed to be compact and inexpensive. □

Gaps filled in porous silicon theory

From Aomar Halimaoui at France Telecom/CNET, 38243 Meylan, France

SINCE it was discovered by A Uhlir at Bell Laboratories in 1956, the "porous" form of silicon has received continuous but moderate study, mainly for dielectric applications such as the electric isolation of silicon integrated devices. Then in 1990 Leigh Canham of the Defence Research Agency (DRA) at Malvern, UK, demonstrated that porous silicon can emit visible light at room temperature. This generated a great deal of interest because of the potential applications in optical interconnect and display technology, and a large number of laboratories all over the world started research in porous silicon. More than 200 papers have been published in the two years since this first report. However, the mechanisms involved in luminescence from porous silicon are still unclear, and there is a vigorous debate concerning its origin.

Porous silicon is produced by dissolving bulk silicon in a hydrofluoric-acid-based solution, which leads to the formation of a network of tiny interconnected pores. These pores completely change the properties of the silicon. Depending on the electrochemical conditions, the width of these pores, and the remaining silicon particles, varies between 2 and 100 nm. The fraction of void (the porosity) ranges between 20% and 90%, and surface areas as high as 600 $m^2 cm^{-3}$ have been reported.

Although most workers now agree that quantum size effects in the "nanocrystallites" which constitute the porous silicon skeleton play a key role in its optical properties, several alternative explanations have also been proposed. A group at the Max Planck Institute in Stuttgart, Germany, for example, has suggested that the luminescence arises from a silicon–oxygen–hydrogen-based compound.

However, the observation of visible emission from porous silicon in contact with hydrofluoric acid (a system that contains only a negligible amount of Si–O according to infrared measurements by Jean-Noel Chazalviel at the Ecole Polytechnique in Palaiseau, France) would seem to contradict this theory. Other alternative explanations, such as the luminescence of SiH_x species or amorphous silicon, require further investigation.

Most of the experiments seeking evidence for the quantum-size-effect model investigate the photoluminescence process (photoluminescence is the emission of light from a material under photonic excitation). But it is clear that other experiments, such as measurements of optical absorption or the dielectric function of porous silicon layers, should give insight into the mechanisms involved. At CNET, for example, we have recently investigated the optical absorption of free-standing porous silicon films (detached from the silicon substrate). The absorption coefficient we measured was shifted towards the visible (a "blue shift") with respect to bulk silicon. In our samples the size of the nanocrystallites decreases as the porosity increases and we found that the shift of the absorption coefficient increased (towards the blue) as the width of the silicon particles decreased. This result is consistent with widening of the band-gap by quantum confinement.

Of the models proposed to explain the optical properties of porous silicon, the quantum-size-effect model is the only one for which theoretical calculations have been made that might answer two basic questions: (i) why is the luminescence so bright? (ii) why is the luminescence in the visible range, and why does it shift from red to green when the porosity is increased?

A J Read and co-workers at Cambridge University in the UK, in collaboration with the DRA group, have calculated the properties of silicon quantum wires (*Phys. Rev. Lett.* (1992) **69** 1232) and used the results to analyse the luminescence properties of porous silicon. They modelled porous silicon as an assembly of silicon wires of rectangular cross section with thickness from 12–27 Å and employed a first-principles pseudo-potential technique. The surface of each silicon wire was assumed to be saturated with hydrogen atoms (this assumption is consistent with experimental data). Their calculations suggest that the fundamental band-gap of a silicon wire structure is both "direct" and larger than the band-gap in bulk silicon (bulk silicon has an "indirect" band-gap which means that when electrons and holes recombine very few are turned into photons). The band-gap also increases as the thickness of the silicon wires decreases. For a quantum wire wider than ~25 Å,

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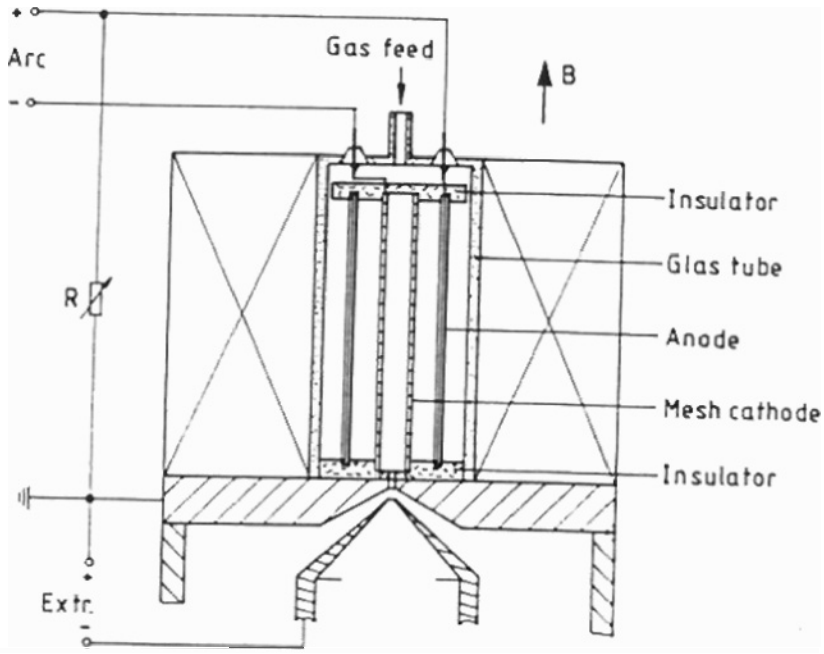

FIGURE 4.5
Hollow-cathode magnetron ion source. (Courtesy of V. Miljević, VINČA, Belgrade.)

Magnetron ion source with axial extraction.'

4.3.2 *Hollow-Cathode Magnetron (Figure 4.5)*

- Special design and construction details of the source

  The hollow-cathode magnetron consists of a diode with two coaxial cylinders placed in an axial magnetic field. A cylindrical anode is around the cylindrical mesh cathode and leaves a free optical axis through the ion source. Anode (18-mm Ø x 60 mm) and cathode (5.5-mm Ø x 60 mm) are insulated to the base flange with the extraction aperture in its center. The discharge plasma is established inside the hollow cathode. When the discharge is established and the base Range connected to the anode, an ion current is obtained even at low accelerating voltages.

- Ion source material and vacuum conditions

  The discharge chamber is a glass tube (30-mm Ø), the anode cylinder Al or stainless steel, the cathode mesh stainless steel *wire* (0.4-mm Ø), eight lines per centimeter, and the insulators are made of lava. The base flange is nonmagnetic.

- Application area of the source

  Accelerators, ion implantation, SIMS, ion beam analysis, optical spectroscopy

- Deliverer or user

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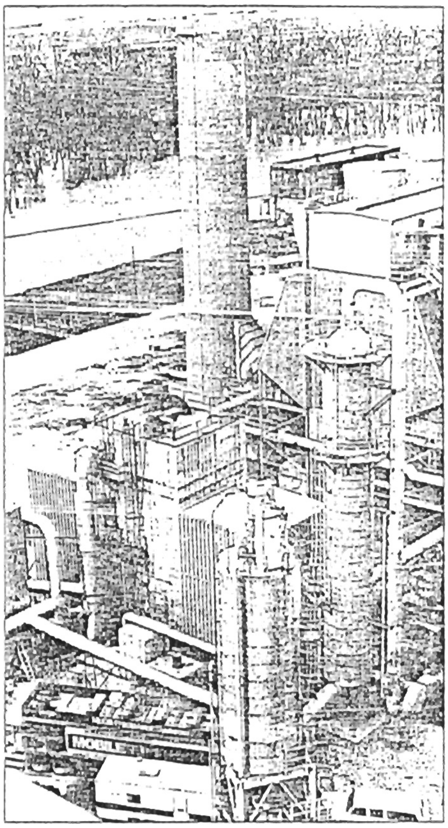

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