Handbook of

ION SOURCES

Edited by

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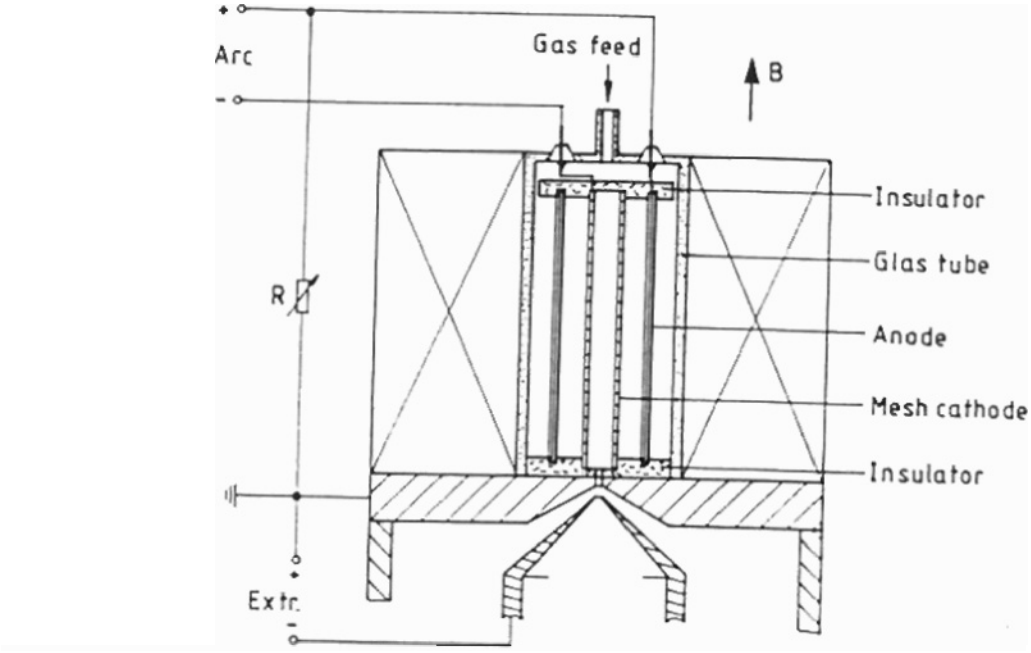

FIGURE 4.5
Hollow-cathode magnetron ion source. (Courtesy of V. Miljević, VIVČA, Belgrade.)

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 *O* x 60 mm) and cathode (5.5-mm *O* 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

  V. Miljević, Institute of Nuclear Science VINČA Atomic Physics Lab., PO Box 522, 11001 Belgrade, Yugoslavia

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 7 700 000 $m^3 hr^{-1}$ 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 unit 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 12–23 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,