Opportunities and Challenges in Technological Plasmas

W. G. Graham

Department of Physics and Astronomy, Queen’s University Belfast, BT7 INN, Northern Ireland

The presentation will be a personnel view of the practical opportunities and intellectual challenges for technological plasmas in emerging and future technologies and in addressing the important issues of energy and the environment.

1. Introduction

This presentation will be a personnel view of the role technological plasmas will play in emerging and future technologies and in addressing some of the most important issues currently facing us: energy and the environment. It will also address the intellectual, educational and structural challenges that must be overcome to deliver the full potential of plasma technology. This abstract provides an overview of some of the issues which will be discussed and illustrated in the presentation.

The phrase “technological plasmas” has surfaced recently as a collective term for the broad spectrum of gas discharges which find application in products, industry and services. It includes everything from high current, arc-based metal smelters to small, cool discharges that can be used in contact with the tissue of conscious humans. The term generally excludes the very hot, highly ionized plasmas created in for example laser-produced and fusion-related plasmas. All the plasmas under the technological plasma umbrella are of potential interest to the ICPIG community.

The increasing broad spectrum of applications comes from the unique physical and chemical environment that plasmas can create. The possible constituents of a plasma system i.e.
- electrons
- positive ions (atomic and molecular)
- negative ions (atomic and molecular)
- electronically excited atoms and molecules and ions.
- rovibrationally excited molecules/neutral, positive, negative)
- photons ( VUV to Far IR)
- dissociation products (atomic, molecular/neutral, positive, negative)
- associative products (excimers/clusters/dust)
- process products (atomic, molecular/neutral, positive, negative)
- contact surfaces
illustrate their technological potential. The list also illustrates the extent of the scientific and engineering challenges in trying to understand the fundamental processes in such plasmas and in optimising them for specific applications.

2. Current applications

There have been several national reviews of the role of plasma science in the industrial, commercial and academic field over the last decade. Two examples are the US National Research Council’s extensive 1995 report “Plasma Science: From Fundamental Research to Technological Applications”[1] (currently being updated) and the 2001 German Federal Ministry of Education and Research’s report “Plasma Technology: Process Diversity and Sustainability” [2].

There are also numerous general and more specific reviews in textbooks [3-5], journal articles [6] and conference proceedings [7]. Those referenced are only some of the more recent examples, to provide a flavour of the current science and technology.

Drawing out some broad trends in the application and study of technological plasmas over the last 30 years there had been a move from arcs and sparks to work on the development of high efficiency lighting, gas lasers, tools for microelectronics manufacturing and recently into soft material processing, including tissue and cells. The focus moved from the relatively high gas pressures of the gas laser to the low gas pressure requirements of anisotropic etching and is maybe now returning to the high pressure plasma systems for displays and materials processing. Basic collision phenomena, inorganic chemistry, instabilities, negative ions, metastables and surface effects have always featured throughout. We are now having to learn some organic chemistry.

The simple wire probes and photomultiplier tubes have been now augmented by laser-aided and optical imaging diagnostics. Analytical models now exist alongside computer-based simulations. Interestingly much of this is due to the advances in lasers and microelectronics enabled by the community’s earlier work.
The advances in diagnostics and simulation has seen the fundamental science of technological plasmas advance enormously. We are part of an increasingly important area of the sciences which has demonstrated an ability to produce, characterise and simulate highly complex systems and processes.

3. Opportunities

Even a list of the future opportunities for technological plasmas would be too long to reproduce here. However some those that will be discussed in some detail are described briefly below.

Micro and nanotechnology will continue to provide challenges to the plasma community with a drive to ever smaller feature sizes, new materials e.g. metals, low and high k dielectrics, porous materials and polymers and emerging challenges such as the growth of straight and functionalised nanotubes.

In lighting there is the requirement to move mercury-less, higher efficiency lighting, albeit with strong competition from solid state devices.

The effect of plasmas on gas and liquid flow is an emerging area if interest in aerospace and microfluidics.

There is huge potential for innovation in the treatment of hard and soft materials. For example adding high value to cheap bulk materials through surface modification. This can be in the form of deposition of thin layers or alteration of the surface bonds or morphology. This can help create biocompatible and bio-degradable coatings, barrier layers and conditions to promote or discourage cell.

In the biomedical area plasmas already play an important part in sterilisation but there is exciting potential for direct use of plasmas to influence cell behaviour.

However perhaps it is in the field of energy and environment that all science and technology faces its greatest challenge. Most scientists now believe that global warming is a serious threat to our planet. Not only may our current energy sources be contributing to that warming but these sources are quickly diminishing. There is an obligation on all scientific disciplines to try to find innovative solutions to these problems.

Our community are clearly contributing in seeking increased lighting efficiency. A 7% increase in efficiency would result in 200 billion kWh reduction in energy and reduce annual carbon production by about 500 million tonnes. Plasmas can help in pollution reduction from power stations and vehicle emission and significantly reduce solvent use. In energy generation play a pivotal role solar cell production and can contribute to an understanding of edge plasmas in fusion devices. They also play a role in hydrogen production. Can we do more on this issue?

4. Challenges

The full potential of all these opportunities will only be realised with a fuller understanding of the underlying science of the plasma sources and devices. This is a huge undertaking but maybe can be contained in two of the grand challenges:

- real-time control of plasmas, possibly through an approach combining relatively simple sensors with computer models,
- developing design rules for engineers so that plasma systems are “fit for purpose” rather than derived from existing technology.

In addition many future applications will require the use of plasmas in multi-phase systems for example in or above liquids, with injected aerosols or with packed bed reactors, we need to our studies into these areas, developing diagnostic tools and models.

However, perhaps the most difficult challenge will be in finding motivated people to take the research forward. The general trend away from the study of the physical sciences and the nature of the funding of particularly the universities, means that the choice of 16 year olds is influencing the research strategy of nations.

Although this is a personnel view, the author acknowledges insightful discussions with Mike Hopkins, Gerrit Kroesen and Mark Kushner.

References