

# Development of Biomedical Applications of Non-equilibrium Plasmas and Possibilities for Atmospheric Pressure Nanotechnology Applications

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**Abstract** - In this paper we discuss the synergisms between different realms of plasma supported nanotechnologies. First the developments in plasma etching for micro and later nanoelectronics have fueled immense growth of knowledge and tools in describing non-equilibrium plasmas. This has led to detailed predictive codes and that knowledge has been used to develop a large number of new sources of non-equilibrium plasmas operating at atmospheric pressure, even in air. With those tools a new front of plasma medicine has opened wide with new possibilities and a number of promising techniques for sterilization, cancer treatment, oral cavity treatment, dermatology and in a range of applications where deposition of thin films for biocompatibility is necessary. This new front opens new possibilities in the realm of nanotechnologies with atmospheric pressure deposition of nano-structures allowing direct application of new techniques in medicine and in cheaper technologies for other purposes.

## I. INTRODUCTION

Non-equilibrium plasma etching and related plasma processes [1] have proven to be the key to achieving manufacturing of integrated circuits, adherence to Moore's law and fueling of the global economy through explosion of all fields of economy that may benefit or even be generated with a strong dependence on processing power. The most important steps in developing of modern micro-electronic technology were achieved by empirical industry based research and science came in later to explain. Having said that, we must acknowledge a lot of successes in continuous improvements of the technology that were made, based on scientific development of diagnostics, modeling and fine tuning of key steps, such as multi frequency [2] and pulsed operation [3]. Finally science has made a significant contribution to understanding and

removal of defects caused by the plasma itself or by the ever increasing demands in miniaturization. The contribution of science nevertheless boils down mainly to **BETTER UNDERSTANDING** of non-equilibrium (low temperature, cold...) plasmas. Most directly this understanding spills over to predictive models [1,4,5] that have been developed for complex geometries, complex chemistries and powering sequences and may represent realistically most of the low pressure industry devices.

At the same time there are constant reminders from the cost aware practitioners that operation of plasma devices is expensive, partly because of the need to have low pressure operation with vacuuming system to ensure the purity of gases. Operating pressures in industry are typically from few to 200 mTorr and purity of the gas that has to be achieved requires pumping down to very low pressures before the gas flow is started. Thus plasma devices operating at atmospheric pressure have been the holy grail of the industry, although some processes are not much cheaper and also cleanliness of substrates may require operation in pure gases maintained in sealed vacuum tight systems (albeit with somewhat smaller restrictions on pumping). Finally vacuum systems make production line manufacturing more complicated. In any case high pressure operation of plasma devices would be a welcome addition to the existing battery of plasma devices that micro-electronics industry has at its disposal.

Nano-particles worthy of scientific interest have been discovered first in atmospheric pressure thermal plasmas, but later non-equilibrium plasmas were shown to give some advantages and additional features [6,7]. While there are other processes that produce nano-particles, still one out of five significant papers in this field comes from the plasma background in one form or the other. Thus nanotechnologies are strongly connected to plasmas, especially non-equilibrium, and in all cases operation at atmospheric pressure would be beneficial.

Atmospheric pressure discharges and plasmas have been known in nature and have been generated by humans for the last 200 and more years. However, most of these plasmas are thermal which in principle means that electrons, ions and gas molecules tend to have the same temperature. When we calculate what is needed for ionization in order to maintain plasma, those are enormous temperatures. Yet maintaining plasma does not require all

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