Ulster University

NIBEC
Nanotechnology & Integrated Bioengineering Centre

Plasma kinetics for plasma medicine applications in cancer treatment

by

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Plasma Medicine

- Plasma medicine is the intersection of plasma science and technology with biology and medicine for:

  - Plasma based sterilization (e.g. for medical devices)

  - Direct therapeutic plasma applications (e.g. for wound healing)

  - Plasma modification of biomedical surfaces (e.g. for hip implants)

- **Cancer treatment**
- **Blood coagulation**
- **Dentistry**
- **Orthopedics**
- **Wound healing**
- **Skin disease**

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Con. Background

- Examples of **traditional therapies** for cancerous diseases are surgical extirpation, chemotherapy and radiation

- These therapies have a **limitation** in use with cancers due to their significant side effects
  - The immune system becomes further compromised
  - The cancer may return for a second time

Non-thermal atmospheric pressure plasmas (N-APP) offers great efficacy, less side-effects for various plasma medical treatments

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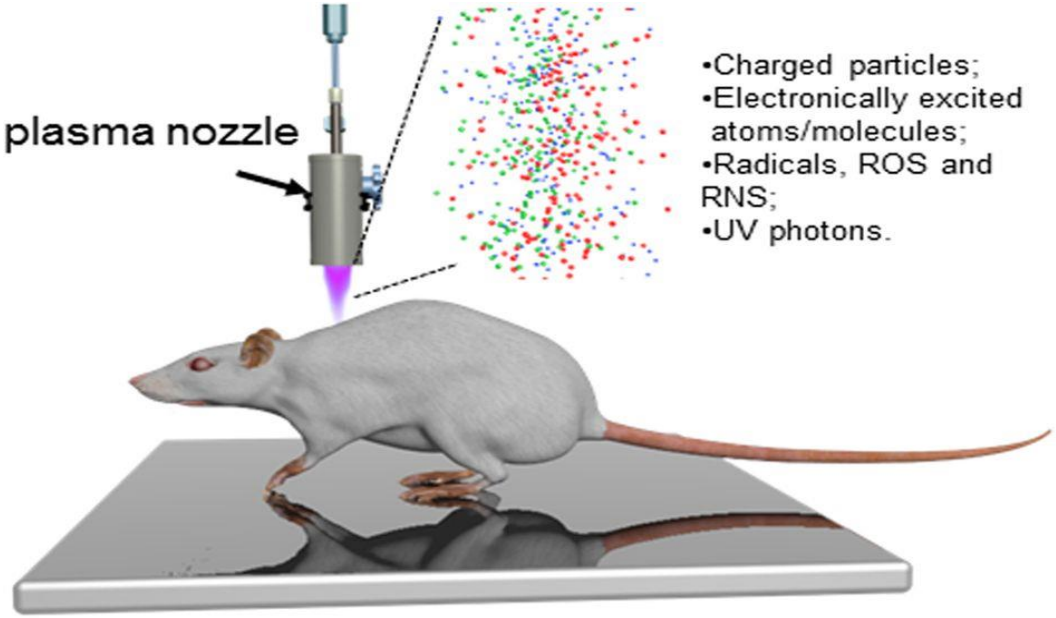
Con. Background

- Plasma interactions with liquid produce same excited **species** in liquid as found with **radiotherapy** BUT at much lower energy.
- Needs systematic study of **plasma – liquid** chemistry and biological interactions
- From radiology studies **DNA damage** is due to the production of short-lived reactive hydroxyl radicals (OH).
- Low energy electrons (**LEEs**) may play a critical role. Still controversial. Difficult to create low energy electrons in liquid



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Plasma Treatment Inside the Body?

❖ Options?

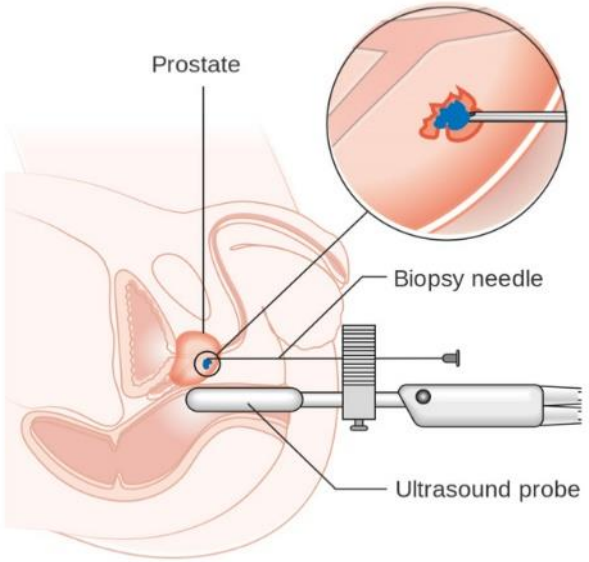
- During surgery (including minimally invasive)
- Endoscopy: flexible tubing
- Long metal needle
- **Injection – Plasma Activated Liquids**

➢ **Endoscopy**

➢ Remote plasma

Plasma generated at end of long tube

➢ **long tube plasma**



❖ Challenges

- High voltages inside the body
- Possible high temperature arcs
- Unwanted tube & parasitic discharges
- Tube erosion

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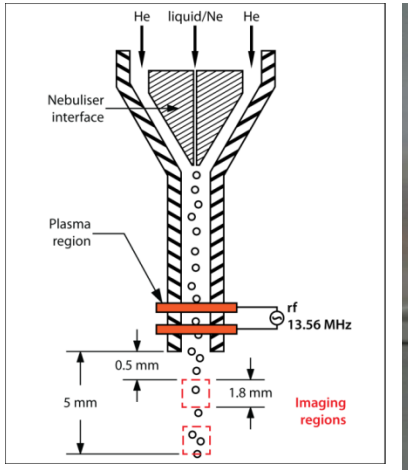
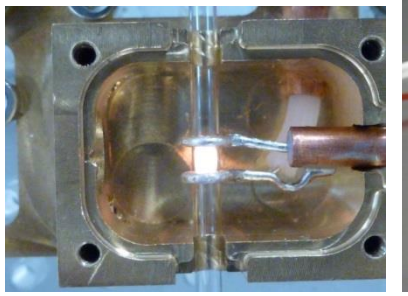
Plasma droplet system

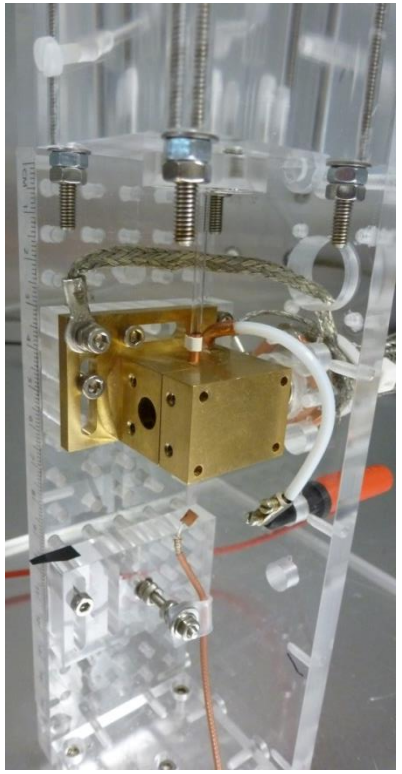
- Droplets (15um) exposed to plasma for 100 us (Limited evaporation)
- Allows study of specific radical reactions (OH, H, HO_2 etc) with well-defined droplet surface

➢ Tests?

- Droplets contain plasma activated liquid, can be transported to tissue in less than 1 ms. **radicals** have limited decay?
- surface is irradiated with high flux of ultra LEE (<0.1 eV). test **LEE** interactions with **DNA**?







RF 13.56 MHz, He: 3.5 slm, Ne (aerosol): 1 slm *or* Ar (aerosol): 1 slm

Maguire et al., Appl. Phys. Lett. 106, 224101 (2015);

Water vapour in plasmas can cause rapid/uncontrolled gas temperature increase – we need to continuously monitor and control this, without interfering with droplets

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Continuous and reliable measurement of gas temperature in APP is critical for future applications

Such as

plasma medicine **&** **food & agriculture** **&** **nanomaterials synthesis**

- A controlled heat is required for the treatment of heat sensitive surfaces, in many biomedical and material applications, e.g. wound tissue and polymers

- The gas temperature is sensitive to many factors that are **rarely** well-controlled especially with the inclusion of molecular gases and water

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Objectives

- Continuous & accurate **gas temperature** measurement of atmospheric pressure plasma jets (APPJ)
- Determining gas temperature in the presence of **microdroplets** / aerosols
- Studying the **chemical analysis** of plasma exposed microdroplet
- Treating **DNA** (in liquid) samples by plasma and studying the resultant damage
- Monitoring the effect of low energy electrons (**LEEs**) generated by the plasma on the damage of DNA cancer cells

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- Gas temperature against RF net power in He without and with microdroplets using **IR sensor**

Flow rate: 1.5 slm

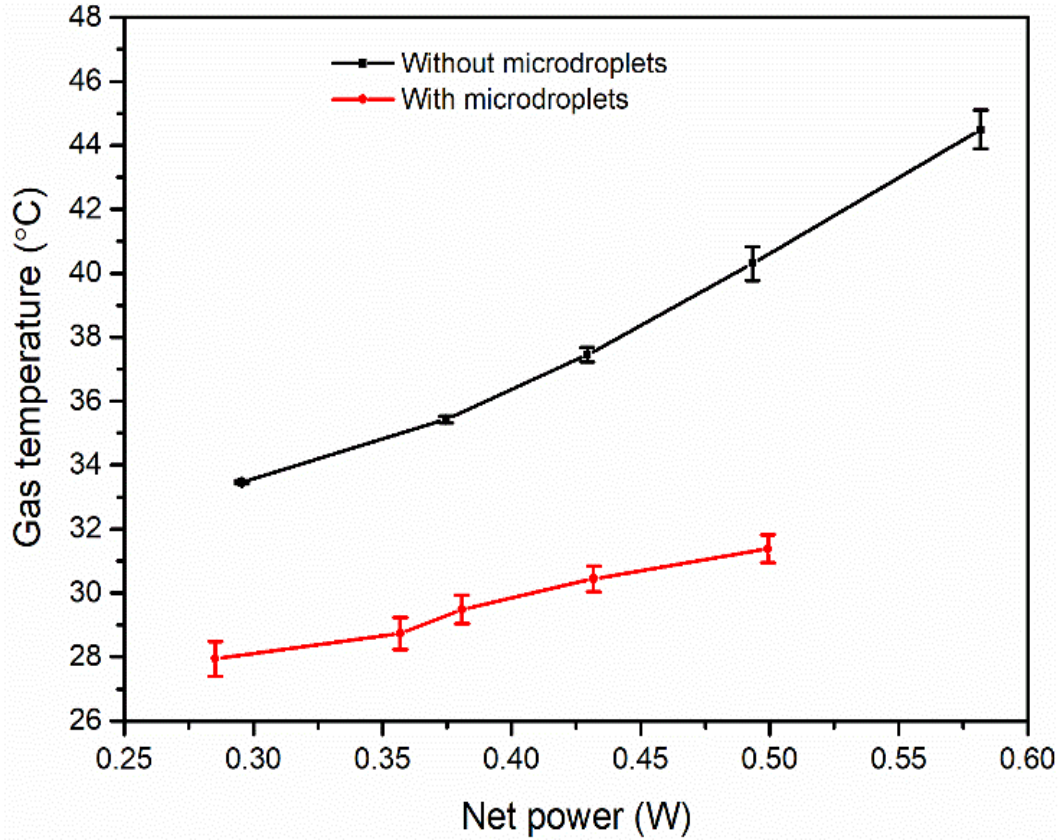
Microdroplets:

av. diameter 12 μm – 15 μm

Av. Velocity: 10 ms^{-1}.

Rate: ~10^5 s^{-1}.

Liquid flow: 10 μL min^{-1}.



Maguire P, et al. Continuous In-Flight Synthesis for On-Demand Delivery of Ligand-Free Colloidal Gold Nanoparticles. Nano Lett. 2017 **17** 1336-1343. Https://doi.org/10.1021/acs.nanolett.6b03440

Maguire PD et al., Controlled microdroplet transport in an atmospheric pressure microplasma. Appl Phys Lett. 2015 **106**. Https://doi.org/10.1063/1.4922034

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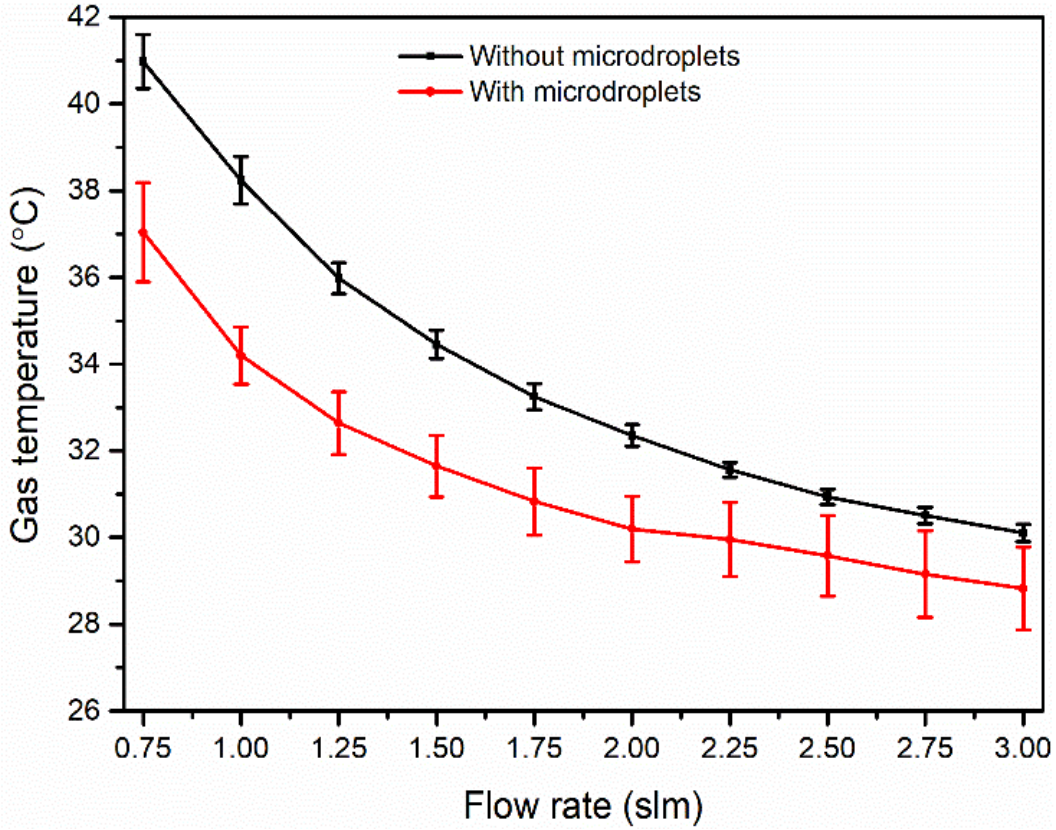
- Gas temperature versus total He gas flow rate with and without microdroplets

at a fixed RF power of 0.3W



✓ The **maximum temperature** reached was <50°C and the introduction of microdroplets, led to a reduction in gas temperature of up to 10 °C. **SAFE!**

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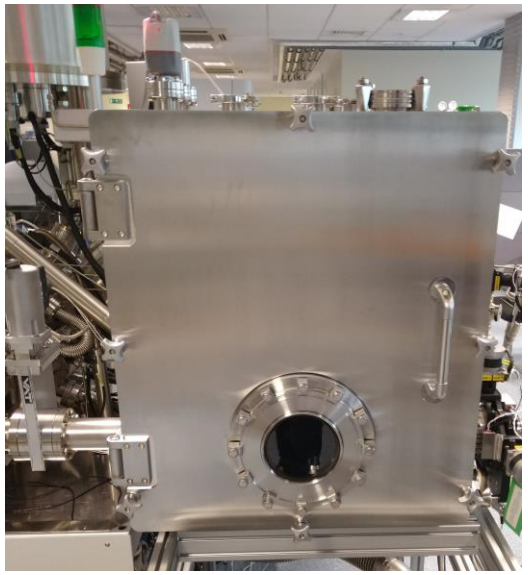
Plasma attachment (PAD)

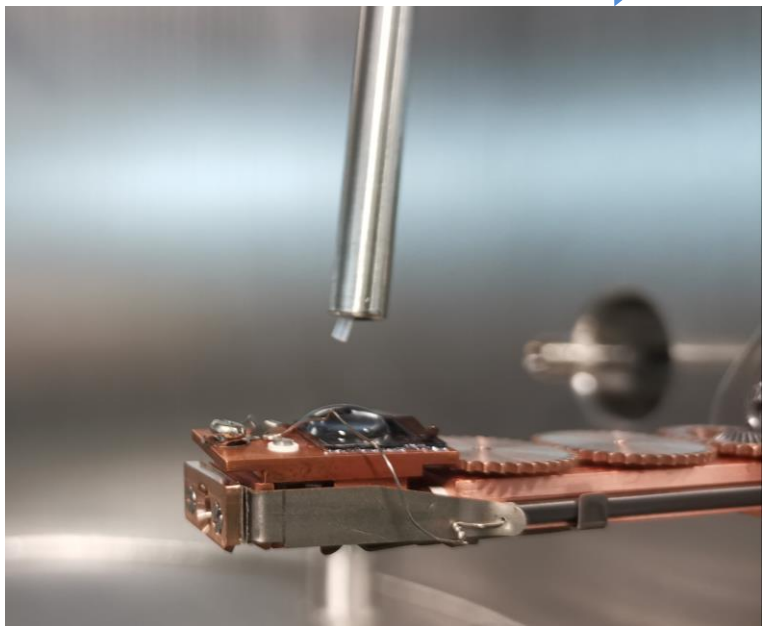
- PAD is a custom-designed load-lock vacuum chamber as an attachment of X-ray photoelectron spectroscopy (XPS) system
- It's the only instrument (**in the world!**) for:
  - ✓ plasma synthesis of nanoparticles
  - ✓ plasma – droplet treatment



➢ Plan

- to pass **droplets** through plasma onto a cold stage (-100 °C)
- transport droplets into **XPS** to determine surface chemistry
- for further study, XPS contains molecular beam sputtering, REELS (electron bombardment) and ISS (He ion bombardment)

BN: This system is still being built by ….. Me!



Conclusion

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- The use of plasma-exposed **microdroplets** has vital potential for delivering plasma-activated liquids and boosting rapid nanomaterials synthesis
- Plasma droplet system is our proposed solution to use **remote plasma**, with high radical flux, for plasma treatment **inside** the body
- **PAD-XPS** system will enable us to perform plasma **treatment** of bulk liquid and **analysis** its chemical characteristics
- Study and control of **gas temperature** and evaporation kinetics will support application e.g plasma medicine, agriculture and microreaction chemistry

For more information on using IR sensor for plasma gas temperature measurement:
N Hendawy et al 2020 Plasma Sources Sci. Technol. 29 085010
https://iopscience.iop.org/article/10.1088/1361-6595/aba2aa

Thank you