Research Activities on Plasma Technology at Canadian Nuclear Laboratories

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Abstract: Canadian Nuclear Laboratories (CNL) have undertaken research activities on the development of low and high temperature plasma systems to perform a variety of plasma processing experiments on nuclear materials. This paper presents a brief description of CNL's plasma research activities, the current plasma experimental systems on site and a summary of some plasma experimental applications in the nuclear field.

Keywords: PPJet, Helicon, DC Plasma, Nuclear Materials.

1. Introduction

Plasma processing has found widespread application in materials processing, including the fields of semiconductor manufacture [1], the synthesis of nanoparticles [2], and the synthesis of advanced manufacturing powder [3]. Plasmas can produce materials that are not otherwise obtainable, since the plasma environment alters the normal pathways that chemical systems take from one stable state to another.

As part of the Federal Science and Technology program, Canadian Nuclear Laboratories (CNL) have undertaken research activities on the development of plasma systems for nuclear applications,

This paper presents a brief description of CNL's plasma research activities, the current plasma experimental systems on site and a summary of experimental applications in the nuclear field.

2. Experimental Plasma Systems at CNL

Both low and high temperature plasma systems have been recently developed at CNL, to perform a variety of experiments on plasma processing of nuclear materials. Low temperature plasma systems include a Helicon plasma system and an Atmospheric Pressure Plasma Jet (APPJ). These systems are being applied to surface modification and thin film coatings of Zircaloy cladding to improve oxidation resistance under high temperature steam conditions for Accident Tolerant Fuel (ATF). High temperature plasma systems include two direct current (DC) plasma systems. These systems are being applied to the synthesis of fuel nanoparticles, advanced TRISO fuel manufacturing, advanced fuel manufacturing, as well as synthesis of carbon-based nanostructures for energy applications.

2.1. Low temperature plasma systems

a) Helicon plasma system

Figure 1 shows a picture of the main components of the Helicon Plasma System. The plasma system includes a plasma glass chamber, a Nagoya type III antenna, a 1.2-kW, 13.5-MHz radio frequency (RF) power supply, a matching network, a solenoid, and a 1-kW direct current (DC) power supply. The reverse power from the antenna is minimized by tuning a matching network through a computer program. The system also includes a stainless steel (SS) coating chamber equipped with characterization and coating feedthroughs.

Fig. 1. Helicon Plasma System Experimental Set-Up.

b) Atmospheric pressure plasma jet (APJet)

Figure 2 depicts a picture of the APJet acquired from APJeT, Inc. It consists of two coaxial electrodes. The central electrode is powered by a 1.2 kW, 13.56 MHz RF power supply, while the external electrode is grounded. The power supply output is matched to the plasma jet impedance by an automatic matching network. A plasma discharge is established in the annular gap between the biased and grounded electrodes. Precursors are injected into an alumina feed tube and enter the ionised gas stream at the exit aperture. A workpiece is positioned approximately 2-20 mm downstream.

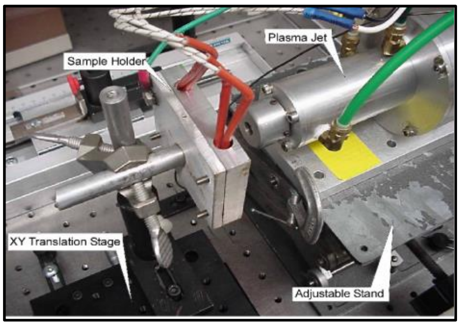

Fig. 2. APJet Experimental Set-Up.

2.2. High temperature plasma systems

a) DC plasma system

The experimental plasma reactor developed in this project is based on the use of a 40 kW DC plasma torch (Praxair SG-200). Figure 3 depicts the DC plasma system experimental set-up.

Fig. 3. DC Plasma System Experimental Set-Up.

The plasma torch, utilizing a high frequency starter to initially generate the plasma, is connected to a 20-kW DC power supply. A pump is used to maintain the experiment's partial vacuum pressure in the reactor. Exhaust gases are cleaned by passing through a series of adsorption traps before release into a fumehood. Depending on the application, inert (Ar, He) or chemically active gases (N_2, H_2, CH_4, etc.) may be used as plasma gases. Solid or liquid reactant mixtures are fed radially to the plasma torch.

3. Plasma Applications

CNL's plasma systems are currently being used in various nuclear material applications. For instance, low temperature systems are used in surface modification and growth of ZrO_2 thin films [4] and diamond-like carbon (DLC) on Zircaloy cladding [5] for accident tolerant fuel applications. High temperature systems are used for ceramic powder treatment to improve nuclear fuel fabrication, synthesis of carbon-based nanostructures for applications related to hydrogen energy storage and hydrogen isotope separation, and volume reduction of highly acidic liquids containing dissolved radionuclides. Table 1 shows current and future potential applications envisaged for the different plasma systems.

4. Conclusions

Canadian Nuclear Laboratories has established a plasma laboratory dedicated to the design and study of plasma reactors for nuclear applications. Both low and high temperature plasma system are being developed. Current CNL's plasma applications include diamond-like carbon and MAX phase coating of Zircaloy cladding for accident tolerant fuel, and nanoparticle synthesis in support of advanced fuel manufacturing, hydrogen isotopes technology, and waste treatment.

Table 1. Potential plasma technology applications

Plasma System	Application
Helicon	· Coating of metallic nanoparticles · MAX phase film coating on Zircaloy cladding · Etching of ceramic and metallic materials · Surface decontamination
APJet	· Coating of metallic nanoparticles · MAX phase film coating on Zircaloy cladding · Etching of ceramic and metallic materials · Surface decontamination
DC	· Plasma-assisted mass filtering system for isotope separation · Synthesis of fuel nanoparticles for advanced manufacturing applications · Plasma chemical separation of nuclear materials · Plasma-assisted chlorination for the synthesis and separation of nuclear materials for molten salt fuel applications · Synthesis of carbides and nitrides and TRISO for advanced fuel applications · Synthesis of carbon-based nanostructures for energy applications · Treatment of radioactive waste (liquid, slurries and resins) · High temperature coating of ceramic and metallic materials

5. References

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