White Paper for *Frontiers of Plasma Science Panel*

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Indicate the primary area this white paper addresses by placing "P" in right column.
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	"P", "S"
• Plasma Atomic physics and the interface with chemistry and biology	
• Turbulence and transport	
• Interactions of plasmas and waves	
• Plasma self-organization	P
• Statistical mechanics of plasmas	S

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	"X"
Oral	X
Poster	
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Title:	**Probe Diagnostics Development for Collisional, Anisotropic and Magnetized Plasmas**
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**(Limit text to 3-pages including this form. Font Times Roman size 11.
1 page of references and 1 page of figures may also be included. *Submit in PDF format.*)**

- ***Describe the research frontier* and importance of the scientific challenge.**

The electrical probe (Langmuir probe) introduced by Langmuir [1] has been the major plasma diagnostics tool for a century. It was mostly by means of Langmuir probes and the plasma spectroscopy that contemporary knowledge of the gas discharge plasmas has been obtained. Langmuir probes have also been extensively used for diagnostics in the basic plasma experiments and in industrial plasma devices operated at relatively low gas pressure. Basics of the electrical probe technique covering various aspects of Langmuir probes, including measurement of electron energy distribution function, EEDF, are given Refs.[2-10].

Comparison analysis of plasma parameters inferred from classical Langmuir probe procedure, from different theories of the ion current to the probe, and from measured EEDF using double differentiation of the probe characteristic revealed a significant discrepancy between plasma parameters obtained by the different probe diagnostics. Analysis[11] of the published experimental material showed that basic plasma

parameters, the electron temperature, T_e and the plasma density, n inferred using the classical Langmuir procedure could be in error due uncertainty in the plasma potential, arbitrariness in the ion current approximation, and non-Maxwellian EEDF. Similar comparison of plasma parameters found from ion part of the probe characteristic using orbital and radial motion theories with those calculated from the measured EEDF demonstrates up to order of magnitude divergence in the plasma parameters. Such disagreement is due to many assumptions in the ion current theories that are not hold in a real experiment, such as ion collisions, a non-Maxwellian EEDF and many others. It was shown that careful EEDF measurement is the only reliable probe diagnostics matching accuracy requirements of contemporary science for highly non-equilibrium gas discharge plasmas at low gas pressure.

The application of probe measurement technique for finding EEDF, according to Druyvestein formulation[12], is only valid for low gas pressures and isotropic electron velocity distributions, EVDFs. When electron anisotropy is weak both conditions are satisfied for bounded gas discharge plasmas over wide range of gas pressure (few mTorr to few Torr) given that probes are properly designed.

However, essential anisotropy occurs at very low gas pressure or/and at some special conditions of strong non-locality in electron kinetics in strong electromagnetic field, and Druyvestein technique for finding EEDF is not applicable. Similarly, Druyvestein technique is not applicable at relatively high gas pressure (collisional plasma), when $\lambda_e \leq (r_p+\lambda_D)$. Here λ_e, r_p and λ_D are, correspondingly, the electron mean free path, the probe radius and the electron Debye radius.

There were attempts to account effects of electron collisions (at high gas pressure), electron non-isotropy (at low gas pressure) and magnetic field on probe diagnostics and, particularly, on EEDF measurements[13-22]. However, no universal and convenient procedure has been developed for EEDF measurement at such conditions.

- ***Describe the approach to advancing the frontier and indicate if new research tools or capabilities are required.***

The challenge for contemporary probe diagnostics is development and validation of robust procedures for reliable probe diagnostics beyond of the area applicability of classic Langmuir and Druyvestein analysis. Unification of existing theories and models for collisional, anisotropic and magnetic field effects on probe characteristics and inferred plasma parameters, collecting comprehensive experimental data base and their comparison with results of independent diagnostics is the main goal of such efforts.

- ***Describe the impact of this research on plasma science and related disciplines and any potential for societal benefit.***

In spite of many books and reviews, where some theoretical estimates and models for probe characteristic at the condition of collisional, magnetized and anisotropic plasmas, there are no so far reliable and acceptable procedure to make such measurement. Development of reliable probe plasma diagnostics beyond traditional applications would brings possibility for accurate and convenient routine to many contemporary devices utilizing high gas pressure and/or magnetized plasmas. Reliable diagnostics is the primary condition for value, impact and social benefit for any experiment.

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