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100-keV FARADAY CUP DESIGN: MATERIALS AND STRUCTURE

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100-keV FARADAY CUP DESIGN: MATERIALS AND STRUCTURE

ABSTRACT

We propose a Faraday cup design for a $1 \text{ mA} \cdot \text{cm}^{-2}$, 100-keV, light-ion-beam measurement in background plasma. Features of this shielded, three-grid structure with deep target are described, and a mechanical draft is included.

In the appendix, we reference and survey results of experiments reporting the number and energy range of secondary electrons and back-scattered ions originating on various metal surfaces bombarded with ~100-keV hydrogen and deuterium ions. Choice of target and grid materials in cup assembly follow from this survey.

DESIGN

The proposed 100-keV Faraday cup design appears in draft form in Fig. 1. Grid-assembly detail and enclosing plasma shield follow in Figs. 2-3. This device was conceived for the time-responsive measurement of an energetic, $1 \text{ mA} \cdot \text{cm}^{-2}$ beam of negative deuterium ions.

FEATURES

Component grid-assembly electrodes and collector cup (identified in the drawing below)

have been arranged with the following functional considerations:

Defining Electrode (D)

This grounded, outer slit admits and collimates a sample of the ion beam into the cup. The polished, conducting face, which is oriented normal to the incident-beam axis, also

- acts as a ground reference for the suppressor (S) potential;
- stops the current produced by the ejected secondary electrons from charging the defining surface; and
- has a knife-edged aperture (see Fig. 2) that minimizes the surfaces exposed at tangential incidence for secondary electron production and buildup in space near the entrance of the device.¹

1. S. Philip, *J. Appl. Phys.* 31, 1592 (1960).

*One washer formed with lobe for electrode attachment.

Fig. 2. Neutral beam, 100-keV Faraday cup — detail of electrode sequence (all dimensions in in.).

Fig. 3. Cover of the Faraday cup.

Suppressor Grid (S)

Negatively biasing this electrode to about -60 V retards low-energy electrons and thus prevents both secondary electrons that originate in the collector cup (C) from escaping and electrons that are produced outside (C) from entering.

Collector Cup Electrode (C)

Electrically connected to the collector cup, this grid intercepts and reflects those high-energy, backscattered ions headed for surfaces that are not a part of the collector circuit (suppressor, insulators). Through successive reflections within the cup, scattered ions eventually decelerate and collect on the cup's surface.

Deep Collector Cup

The solid angle of the entrance opening at collector grid (C) is small:

$\Omega = 2\pi(1 - \cos \alpha) = 0.012 \text{ sr} \ll 2\pi \text{ sr}$. This reduces the current-measurement error due to the escape of secondary electrons and backscattered ions from the collector cup.

Shielding

The heavy line in the electrical schematic in the first drawing above outlines the enclosure of the collector cup, suppressor, and all insulating surfaces by a grounded shield case (Fig. 3), which, together with defining electrode D, acts to eliminate both plasma and stray, charged-particle currents from the cup signal.

Spacing of Electrodes and Size of Apertures

Electrode dimensions and placement are based on a 1-eV plasma background of density comparable to a $1\text{-mA}\cdot\text{cm}^{-2}$ ion-beam density. In this case the electron debye length is only

$$\lambda_{De} = \left(\frac{kT_e}{4\pi n e^2} \right)^{1/2} = 0.074 \text{ cm.}$$

However, with the usual drop of plasma density inside the probe, good field penetration may be expected for up to $10 \lambda_{De}$ spacing. Hence, the average 0.95-cm spacing shown in Figs. 1 and 2 is acceptable.

Replacement of apertured disk electrodes with wire-mesh grids is reportedly subject to surface-impurity buildup.²

Electrode Exposure

The electrode's surface area directly exposed to the beam

is minimized by:

- tapered apertures of adjacent grids, which accept only those beam particles with trajectories lying within a 14° acceptance angle into the collector. This prevents most of the direct beam from striking the edges of the suppressor (S) and collector (C) electrodes, which have larger apertures, yet insures close-to-normal incidence of ion primaries on the target inside (C); and
- thin (0.010 in.) suppressor (S) and collector (C) electrodes.

Insulators

The present design offers ~ 0.100 in. of protection against creeping of charges on surfaces of nylon and Mylar separators.

Construction

A simple design facilitates electrode and target replacement or modification.

Target and Electrode Metals

Choices of target and grid materials follow from a survey of the experiments listed in Appendix A and described in Tables A1-A2. Table 1 compares the materials used in these experiments. The secondary emission

2. J. Simpson, *Rev. Sci. Instrum.* 32, 1283 (1961).

compares the materials used in these experiments. Two separate phenomena are of interest: secondary electron emission and backscattering of incident and/or target ions. The secondary emission mechanism consists of incident particles ionizing atoms in the target; a fraction of the freed electrons possess an energy that exceeds the work function and escape from the target surface. In the case of ion backscattering, binary collisions with target atoms result in ion reflection at high energy. The selected target material should minimize both of these processes.

The collector and defining electrodes are copper, with polished copper used for the collector cup and target. The suppressor is made of molybdenum. Aluminum is an alternative material suggested by the experiments studied.

WTW/gw/wl,la/gw

Table 1. Scattering interactions on target surfaces.

Interaction frequency (rank)	Surface interaction	Primary/secondary	Target materials that minimize interaction (ranked)		Expected scattering factor	Scattered particle energy	Optimum angle of incidence	Measured current (when scattered particle escapes)
1	Secondary emission by D^-		Exp. 1 Al Cu Ag Zr	Exp. 2 Ta Mo Ni	$\gamma_e \gtrsim 3$	Low ($\sim 10\text{eV}$)	Normal	$-[1-\gamma_e]ev_{D^-}$ D^- absorbed; target emits e^- s
2	Secondary emission by D_2^-		Exp. 1 Cu Ag Al	Exp. 2 Ta Mo Ni	$\gamma_e > 5$ governed by surface dissociation	Low	Normal	$-[1-\gamma_e]ev_{D_2^-}$ D_2^- absorbed; target emits e^- s
3	Secondary emission by D_2		Exp. 1 Cu Ag Al γ same as for D_2^+	Exp. 2 Ta Mo Ni	$\gamma_e \sim 5$	Low	Normal	$\gamma_e ev_{D_2}$ Target emits e^- s
4	Non-scattering collision by D^- and D_2^-				0			$-ev_{D^-}$ $-ev_{D_2^-}$ Current collected
5	Primary ion backscattering by D^-		Al } Ti } Cu } Mo }	superior average	$K^- \sim 0.03$	High ($\sim 10\text{keV}$)	Low angle	0 Not counted
6	Primary ion backscattering by D_2^-		C } Mo } Zr }	superior average	$K^- \sim 0.06$			>0 Two negative ions emitted during some collisions
7	Target ions scattered by D^- (sputtering, desorption)		Mo Cu Ag two experiments		$S \sim 0.03$	Low	Low angle	
8	Target ions scattered by D_2^-		Ta		$S \sim 0.07$	Low		
9	Positive or neutral ion scattered by D^- ; or D_2^-		?		K^+ K^0			$-2K^+ ev_{D^-}$ Target absorbs $2e^-$ s $-K^0 ev_{D_2^-}$ Target absorbs $1e^-$

APPENDIX A: EXPERIMENTS STUDIED TO DETERMINE TARGET MATERIALS

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Table A1. Ion-beam secondary-emission experiments.

Parameter	Incident ion	Energy of incident ion	Surface condition	Coefficient of secondary electron emission, γ_e	Scattered electron energy, E	Remarks/conclusions	References
Charge state	H^+	22 keV	Gassy, cold	Mo = 1.38	$E < 5$ eV	Negative ion causes substantial increase in secondary emission over positive ion.	12
	H^-	22 keV	Gassy, cold	Mo = 3.52			
	D_2	40 keV	Hot	Mo $\sim$ 4.8		Primary neutral results in same γ as for corresponding positive ion.	9
	D_2^+	40 keV	Hot	Mo $\sim$ 4.8			
Target materials, incident angle, molecular ions	D^+	100 keV	Cold	Be=3.5 Ag=3.25 Al=3.1 Zr=3.3 Cu=3.25	$\gamma_e \propto \sec \theta$ for D^+ and D_2^+ .		6
	D_2^+	100 keV	Cold	Be=5.7 Ag=4.8 Al=5.3 Zr=5.6 Cu=4.8			
	D^+	1 MeV	Cold	Be=2.3 Ni=1.5 Cu=1.4			7,8
Energy distribution, target materials	D^+	40 keV	Hot	Ta=2.3 Mo=2.5 Ni=2.5 C=3.3	$\bar{E} \sim 10$ eV	D_2^+ has γ about 2 times as large as that for D^+ (when target hot).	9
	D_2^+	40 keV	Hot	Ta=4.4 Mo=4.8 Ni=5.2 C=6	$E < 100$ eV		
	H^+	100 keV		Mo	$\bar{E} \sim 10$ eV		12
	H^+	48 keV		Cu			
Impurities	H^+	100 keV	Cold $\rightarrow$ hot	Mo	$E < 30$ eV	γ decreases with increasing target temperature.	10
						γ higher for gassy surface.	12

Table A2. Ion-beam backscattering experiments.

Parameter	Incident ion	Energy of incident ion, E_0	Scattered particles	Surface conditions	No. of scattered particles Incident ion = K	Energy of scattered particles, E	Remarks	References
Primary charge	H^-	22 keV	H^-	Cold, gassy	Mo $\sim$ 0.020			15
	H^+	22 keV	H^+	Cold, gassy	Mo $\sim$ 0.015			
Reflection energy, target materials	D^+	100 keV	D^+	100°C, clean	Be $\sim$ 0.0003 Al $\sim$ 0.003 Ti $\sim$ 0.006 Cu $\sim$ 0.018 Mo $\sim$ 0.030 (uncertain by a factor of $\sim$ 4)	Ti: Energy distribution peaks at 2 keV with 1/2 peak value at 50 keV. Al: Almost all scattered ions have energy greater than 1 keV.	Cu: K is lowest for low scattering angles; K reaches peak value at 30° from normal incidence.	1,4
Energy distribution	H^+	100 keV	H^+	Hot		Mo: $0.15 E_0 < E < 0.50 E_0$ for most backscattered ions.		5,11
Target surface impurities	H_2^+	10 keV	H_2^+	Cold, gassy Hot, clean	K for cold, gassy surface is $\sim$ 1.4 times that for hot, clean surface.	{ Some particles with $E < 30$ eV No particles with $E < 30$ eV		11
	?	1 keV	?	Gassy			Average E is 1/2 that for clean surface.	
Secondary ions (sputtering, desorption)	D^+	40 keV	Sputtered target ions	Cold	{ Cu = 0.02 Ag = 0.01 Mo = 0.0044 (positive particles = 0.007 (negative particles)		Surface erosion expected to maintain clean target.	2,12
	D^+	10 keV						
	H^+	22 keV	Sputtered, desorbed target ions	Cold, gassy	Mo = 0.0045 (positive particles) = 0.011 (negative particles) Ta = 0.09 (scattered current)		{ Secondary ion emission rate decreases with increasing mass of primary.	15 12
	H^-	22 keV						
	H_2^-	22 keV						
Electron capture (not germane to negative primary ion beam)	D^+	200 keV	D^-	Cold, clean	Cu = 0.0012 Al > 0.0016 Stainless steel = 0.0020 C = 0.0020	$E < 10$ eV		2
			D^+	Cold, clean	K $\sim$ 0.01	$E > 400$ eV		
Molecular primaries	H_2^+	100 keV	H^+ H_2^+	Hot	Mo $\sim$ 0.050 Zr $\sim$ 0.050 C $\sim$ 0.020		Surface dissociation very probable. Most ions reflected as H^+ , few as H_2^+	16
	H^+	100 keV	H^+	Hot	Zr $\sim$ 0.028 Mo $\sim$ 0.025 C $\sim$ no data			

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