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Modified biased split detectors for the HIBP electrostatic energy analyzer

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In electrostatic energy analyzers of heavy ion beam probes the required accuracy of plasma potential measurements is provided by differential detection of the ion beam on the split detector. Secondary electrons created on the detector surface by the analyzed ions and ultraviolet plasma radiation can strongly disturb the measurements. In this article we consider the influence on analyzer operation of secondary electrons emitted from the detector, describe the relation for corresponding errors in the plasma potential measurements, and present two modified biased split detectors which avoid these errors. © *2001 American Institute of Physics.* [DOI: 10.1063/1.1310592]

I. INTRODUCTION

Measurements of plasma potential by a heavy ion beam probe (HIBP) require accuracy of $\Delta E/E_b \leqslant 10^{-4}$, which in electrostatic energy analyzers is provided by differential detection of the ion beam on the split detector. The relation for the value of plasma potential measured by a 30° Proca–Green electrostatic analyzer is[1]

$$\Phi_{\mathrm{pl}} = 2U_a(\delta i F + G_a) - U_b, \tag{1}$$

where U_b and U_a, respectively, are the accelerator and analyzer voltages, $\delta i = (i_t - i_b)/(i_t + i_b)$ is the normalized difference (ND) of the currents on the top (i_t) and bottom (i_b) split plates, and G_a and F are the analyzer gain and dynamic coefficients, respectively, which are functions of the analyzer geometry and entrance angle of the beam.

The actual currents on the split detector are a combination of both the ion and electron currents. The uniform secondary electron emission from the split detector does not influence analyzer operation.[2] However, the different geometry and surface conditions of the split plates and the asymmetric secondary electron exchange between the plates (for example, due to stray magnetic field of a plasma device in the vicinity of the detector) break the uniformity of secondary electron flux and can strongly disturb the measurements.

In this article we present two modified biased split detectors which avoid the effect of secondary electrons on HIBP measurements of plasma potential by electrostatic energy analyzers. It is organized as follows. In Sec. II the relations for the errors in the measurements contributed by secondary electrons are described. Two new detectors and the respective experimental results are presented in Sec. III. Conclusions are formulated in Sec. IV.

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II. INFLUENCE OF SECONDARY ELECTRONS ON HIBP MEASUREMENTS

The currents on the top and bottom plates of the split detector, modified by secondary electrons, can be expressed in general form by

$$\begin{aligned} i_t &= i_{\mathrm{beam}}[\xi(1+\alpha_t) - \alpha_b\beta_b(1-\xi) + k(1-\beta_b)],\\ i_b &= i_{\mathrm{beam}}[(1-\xi)(1+\alpha_b) - \alpha_t\beta_t\xi + k(1-\beta_t)], \end{aligned} \tag{2}$$

where i_{beam} is the sum of the ion current on the split detector; ξ is the balance coefficient that determines the parts of the ion current on the top and bottom collector plates; α_t, α_b, and β_t, β_b are the respective secondary electron emission and electron exchange coefficients; $k = i_{\mathrm{UV}}/i_{\mathrm{beam}}$ is the inverse signal-to-noise ratio of the detector with a noisy signal of uniform secondary electron flux i_{UV}, created by plasma ultraviolet (UV) radiation.

We shall analyze the dynamic curve (DC): (ND) $= \delta i = f(U_b + \Phi_{\mathrm{pl}})/2U_a$, given by Eq. (1). The ideal DC is linear and symmetrically saturated on ± 1, Fig. 1 curve (1). The point on the DC where (ND) $= 0$ is determined by the top–bottom current equality and corresponds to the balance coefficient $\xi_0 = 0.5$. The values of the shift of this point on the beam energy scale contributes to the values of the measured plasma potential. The shifts associated with any effects, except the plasma potential, indicate the errors introduced into the measurements.

The presence of secondary electrons with the properties described by Eqs. (2) generally breaks the linearity and saturation symmetry of the DC, and therefore, disturbs the analyzer sensitivity and shifts the point (ND) $= 0$, Fig. 1 curve (2). The modified value of the balance coefficient ξ_0 now is

$$\begin{aligned} \xi_{0\,\mathrm{mod}} = {} & [\alpha_b(1+\beta_b) + k(\beta_b - \beta_t) + 1]/[\alpha_t(1+\beta_t)\\ & + \alpha_b(1+\beta_b) + 2], \end{aligned} \tag{3}$$

and the shift of the relative point on the ideal DC is found to be

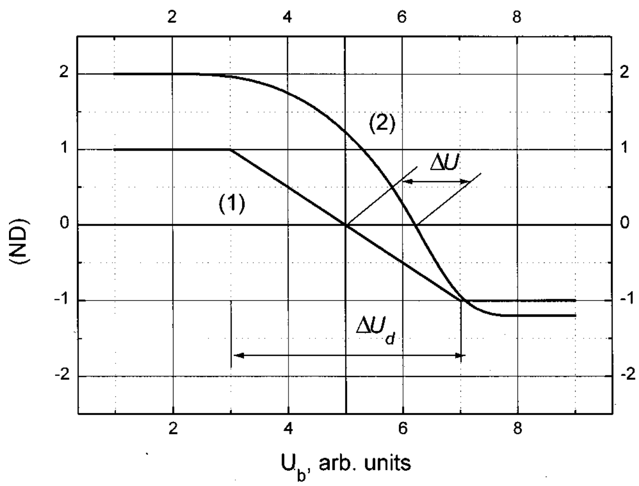

FIG. 1. Ideal (1) and modified by secondary electrons (2) dynamic curves.

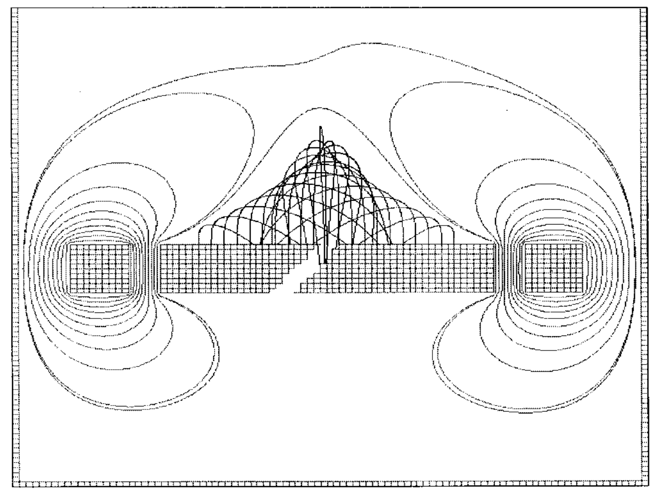

FIG. 3. Lines of equal potentials (50 V on electrodes) and trajectories of 4 eV secondary electrons in the bias detector with symmetric exchange of secondary electrons.

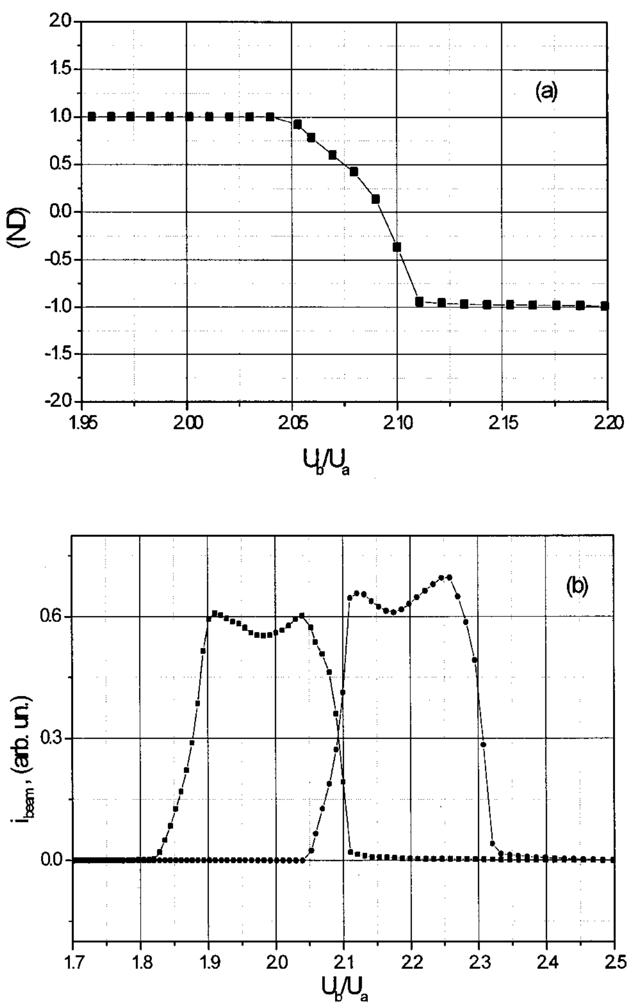

FIG. 2. Dynamic curve (a) and currents (b) on the collector plates of a conventional split detector.

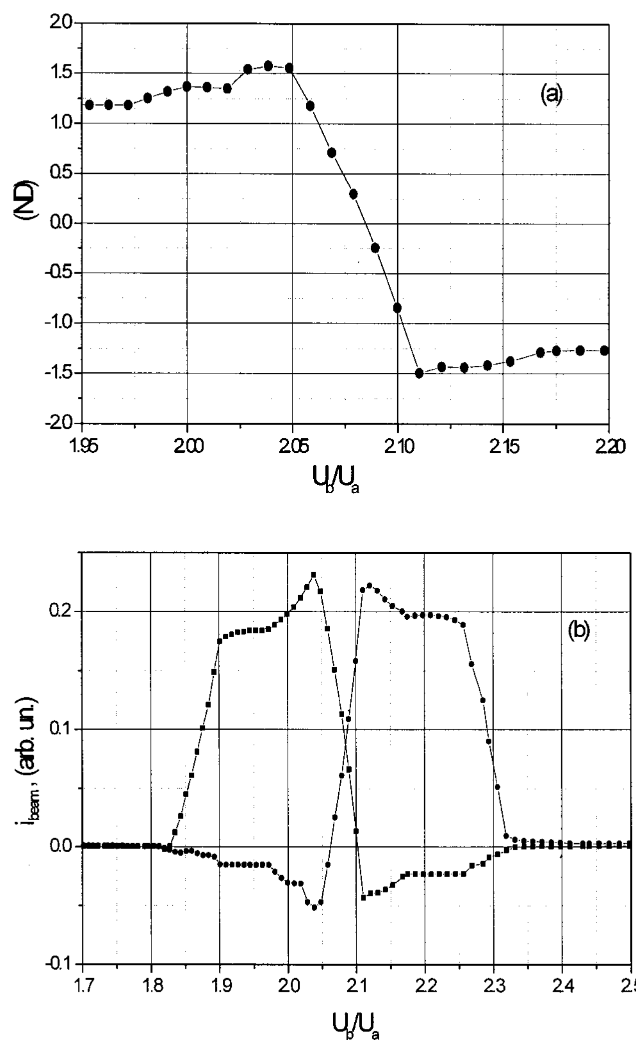

FIG. 4. Dynamic curve (a) and currents (b) on the collector plates of the biased detector with symmetric exchange of secondary electrons.

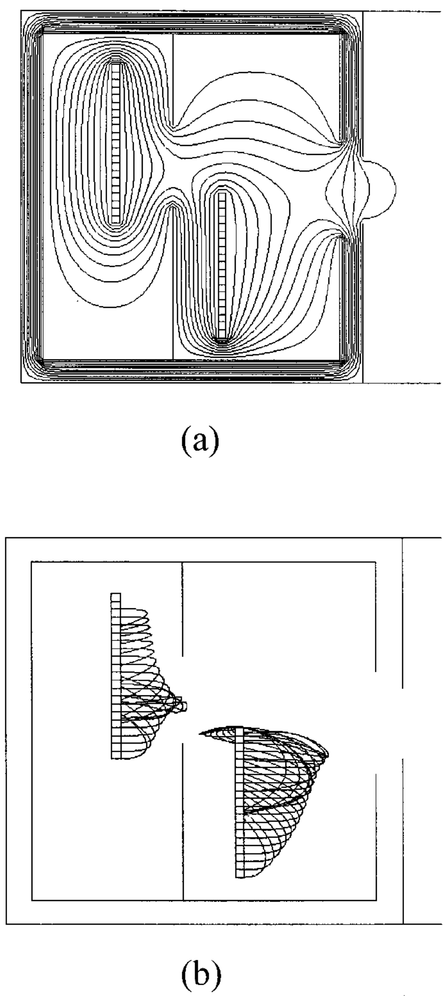

FIG. 5. Lines of equal potentials (100 V on electrodes) (a), and trajectories of 4 eV secondary electrons in the bias detector with full suppression of secondary electrons (b).

$$\Delta U = \tfrac{1}{2}\{[\alpha_b(1+\beta_b) - \alpha_t(1+\beta_t) + 2k(\beta_b - \beta_t)]/ [\alpha_t(1+\beta_t) + \alpha_b(1+\beta_b) + 2]\}\Delta U_d, \quad (4)$$

where $\Delta U_d = 4FU_a$ is the dynamic range of the energy analyzer.

We consider three particular examples.

(1) Nonuniform secondary electron emission without exchange between the plates of split detector: $\alpha_t \neq \alpha_b$, $\beta_t = \beta_b = 0$.

The DC is nonlinear, but still symmetrically saturated on ± 1. The error in the measurements is given by

$$\Delta U = \tfrac{1}{2}[(\alpha_b - \alpha_t)/(\alpha_t + \alpha_b + 2)]\Delta U_d. \quad (5)$$

(2) Uniform secondary electron emission with symmetric exchange between the plates of split detector: $\alpha_t = \alpha_b = \alpha$, $\beta_t = \beta_b = \beta$.

The DC remains linear, but is symmetrically saturated on levels different from ± 1, depending on the correlation among the coefficients α, β, and k. The error in the measurements is zero.

(3) Uniform secondary electron emission with unidirectional exchange between the plates of split detector: $\alpha_t = \alpha_b = \alpha$, $\beta_{t,b} = \beta$, $\beta_{b,t} = 0$.

The DC is nonlinear with asymmetric saturation, depending on the correlation among the coefficients α, β, and k. The error in the measurements is given by

$$\Delta U = \pm \tfrac{1}{2}\{(\alpha + 2k)\beta/[2(\alpha+1) + \alpha\beta]\}\Delta U_d, \quad (6)$$

where the plus/minus sign in ΔU depends on the direction of the electron exchange.

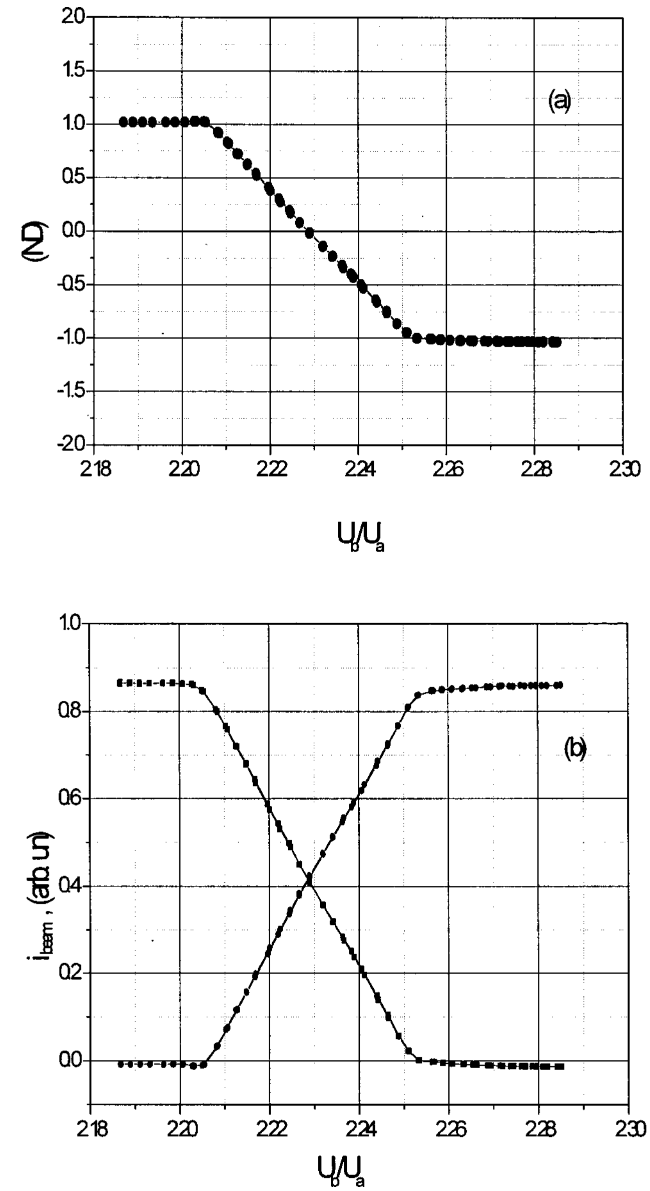

FIG. 6. Dynamic curve (a) and currents (b) on the collector plates of the bias detector with full suppression of secondary electrons.

III. OBSERVATIONS OF SECONDARY ELECTRON EFFECTS: MODIFIED BIASED SPLIT DETECTORS

The influence of secondary electron emission on analyzer operation has been investigated at a test facility[2] by scanning of a 8 keV Cs^+ beam across the plates of the split detector varying the analyzer voltage. Figure 2 shows the DC and currents on collector plates obtained with the simplest unbiased split detector arranged without any shielding below the bottom plate of the analyzer. The saturation of the DC on ± 1 indicates the absence of electron exchange between the plates. The observed nonlinearity of the DC is attributed to disturbance of secondary electron flux uniformity by a stray electric field that penetrated into the unshielded detector through the grid holes in the bottom plate of the analyzer (example No. 1).

Except for full suppression of secondary electron emission, symmetrization of the electron exchange between the plates could be another approach by which to avoid the error contributed by secondary electrons in the measurements (example No. 2). This has been obtained with two additional biased plates arranged externally to the collector ones, as is shown in Fig. 3. Figure 4 presents the experimental DC and the currents on internal collector plates with clear evidence of secondary electrons (negative polarity of the currents). The characteristics of the DC indicate almost uniform secondary electron emission and symmetric exchange of the electrons between the plates. A comparison of Figs. 2(a) and 4(a) demonstrates the influence on the DC of the changes in the conditions of secondary electron emission. The different potentials, independently applied to additional external plates of the split detector, regulate the exchange of electrons between internal plates and allow one to observe DCs with different properties (example No. 3).

The appropriate bias geometry with complete suppression of secondary electrons has been simulated by the SIMION code. The result is shown in Fig. 5. In this geometry two collector plates are enclosed inside the bias box which has two extensions between the plates. The corresponding DC and the currents obtained with this detector at the test facility are shown in Fig. 6 and present practically ideal characteristics.

IV. CONCLUSIONS

The nonuniformity of the flux of secondary electrons emitted from the plates of the split detector can disturb the analyzer sensitivity and introduce a substantial error in the plasma potential measurements. Two elaborated upon modified biased split detectors avoid the problem by the symmetrization of electron exchange between the plates and complete suppression of secondary electrons.

Control of the characteristics of the analyzer's dynamic curve during HIBP measurements is desirable to indicate the influence of secondary electrons on analyzer operation.

[1] L. Solensten and K. A. Connor, Rev. Sci. Instrum. **38**, 516 (1987).
[2] A. V. Melnikov, N. K. Kharchev, L. G. Eliseev, I. S. Bondarenko, L. I. Krupnik, S. M. Khzebtov, I. S. Nedzelskiy, and Yu. V. Tzofimenko, Rev. Sci. Instrum. **68**, 308 (1997).