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QUANTUM WELLS, DOTS, WIRES
AND SELF-ORGANIZING NANOSTRUCTURES
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"Spin and Charge Transfer Instabilities in Semiconductor Double Quantum Wells"

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These are preliminary lecture notes, intended only for distribution to participants.

Spin and Charge Transfer Instabilities in Semiconductor Double Quantum Wells

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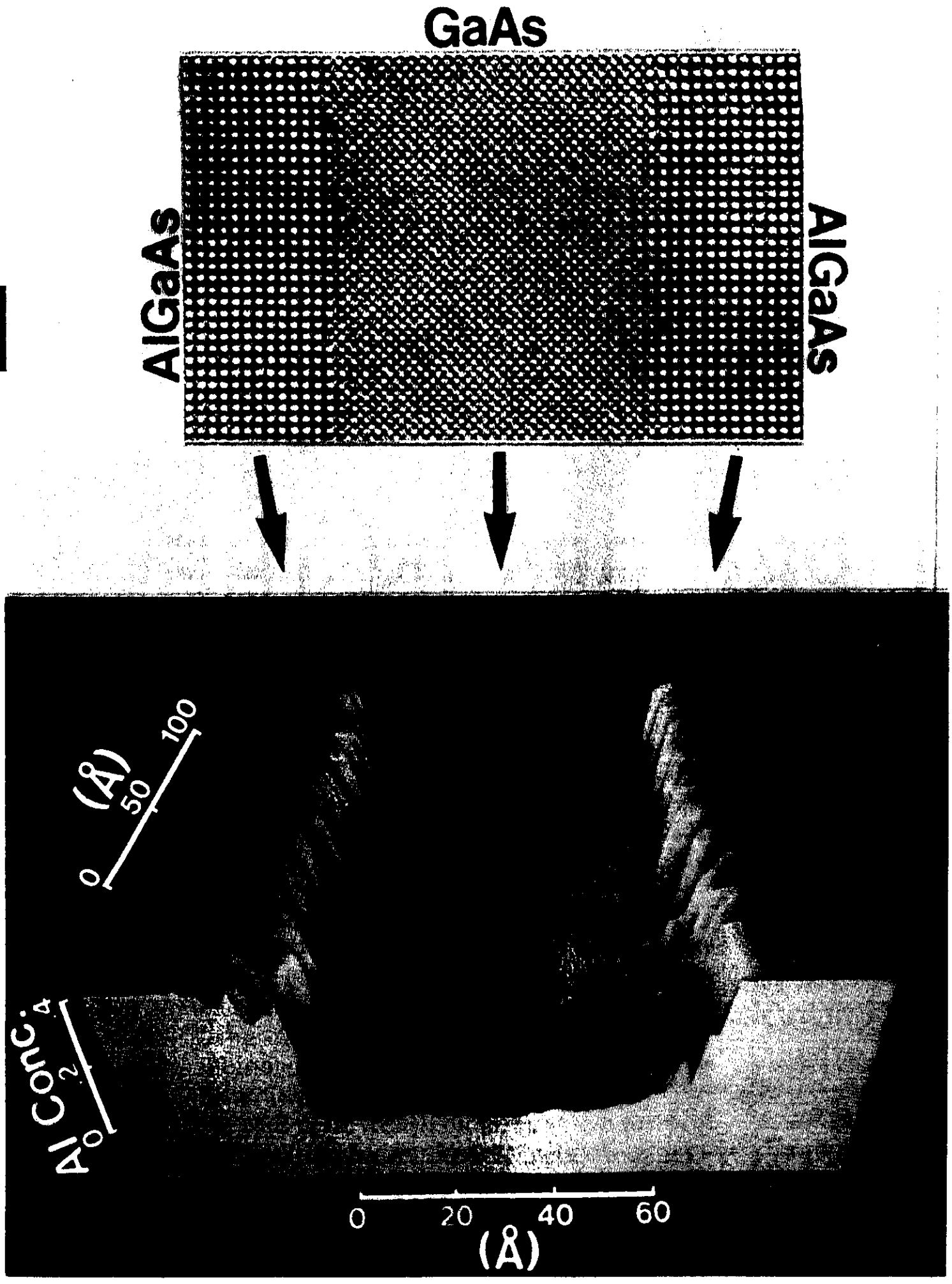

GaAs
AlGaAs
AlGaAs
0
50
100
(Å)
Al Conc.
0
2
4
0
20
40
60
(Å)

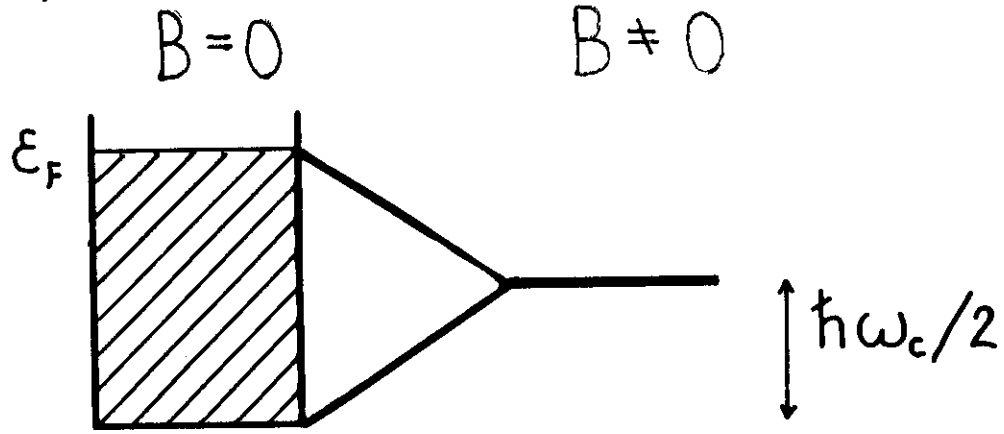
Motivation.

Study the effects of the electron-electron interaction in quasi-bidimensional systems.

$$H = \sum_i \frac{\mathbf{p}_i^2}{2m} + \frac{1}{2} \sum_{i,j(i \neq j)} \frac{e^2}{|\mathbf{r}_i - \mathbf{r}_j|}.$$

Two ways of favoring the potential energy against the kinetic energy:

a) applying magnetic fields (fractional quantum Hall effect).



b) lowering the electronic density (F. Bloch, 1929).

Z. Phys. 57, 549 (192

Monolayer (Hartree-Fock approximation).

$$E^{HF}(n,m) = \left[\frac{1+m^2}{r_s^2} - \frac{4\sqrt{2}}{3\pi r_s}\left((1+m)^2+(1-m)^2\right)\right]\frac{ne^2}{2a^*\varepsilon}$$

where

$$n = n_\uparrow + n_\downarrow \text{ (electrons/unit area)}$$

$$m = \frac{n_\uparrow - n_\downarrow}{n_\uparrow + n_\downarrow} \qquad -1 \le m \le 1$$

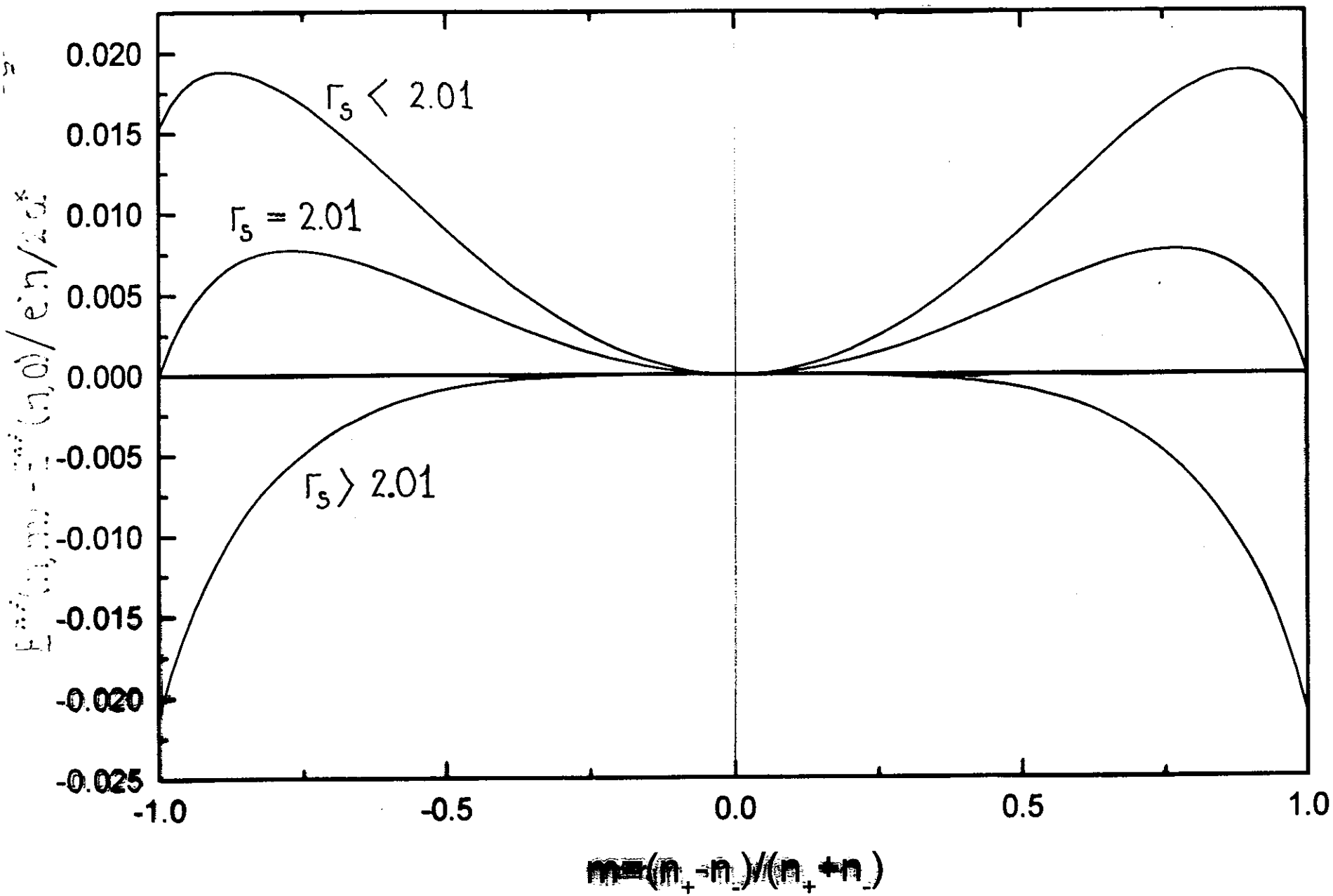
$$r_s = \frac{r_0}{a^*} \qquad n = \frac{1}{\pi r_0^2} \qquad a^* = \frac{\varepsilon\hbar^2}{m^* e^2} \simeq 100\,\text{Å(GaAs)}$$

The transition paramagnetic $\rightarrow$ ferromagnetic occurs when

$$E^{HF}(n,0) - E^{HF}(n,1) = 0 \rightarrow r_s = \frac{3\pi}{8(2-\sqrt{2})} \simeq 2.01$$

For GaAs, $r_s \simeq 2.01 \rightarrow n \simeq 0.8 \times 10^{11}/cm^2$.

Monolayer (H-F approximation)



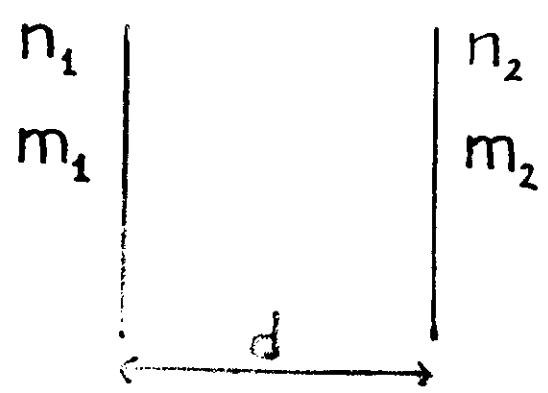
Bilayer (Hartree-Fock approximation).

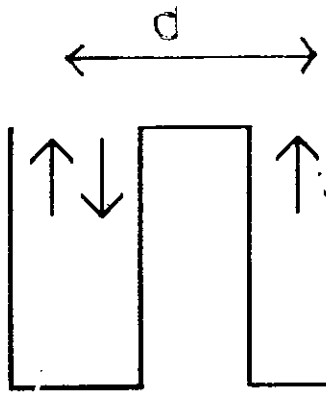
Ruden and Wu, Appl. Phys. Lett. **59**, 2165 (1991).
Conti and Senatore, Europhysics Letters **36**, 695 (1996).
Zheng, Ortalano, and Das Sarma. Phys. Rev. B **55**, 4506 (1997).

$$E^{HF}(n_1, m_1, n_2, m_2) =$$
$$\left[\frac{1+m_1^2}{r_{s1}^2} - \frac{4\sqrt{2}}{3\pi r_{s1}}\left((1+m_1)^2 + (1-m_1)^2\right)\right]\frac{n_1 e^2}{2a^*\varepsilon} +$$
$$\left[\frac{1+m_2^2}{r_{s2}^2} - \frac{4\sqrt{2}}{3\pi r_{s2}}\left((1+m_2)^2 + (1-m_2)^2\right)\right]\frac{n_2 e^2}{2a^*\varepsilon} +$$
$$\frac{2\pi e^2 d}{\varepsilon_{barrier}}\left(\frac{n_1 - n_2}{2}\right)^2.$$

Minimize $E^{HF}(n_1, m_1, n_2, m_2)$ with respect to n_1, m_1, n_2, m_2.

Constraints: $0 \leq n_i \leq 2n$, $n_1 + n_2 = 2n$, $0 \leq |m_i| \leq 1$.





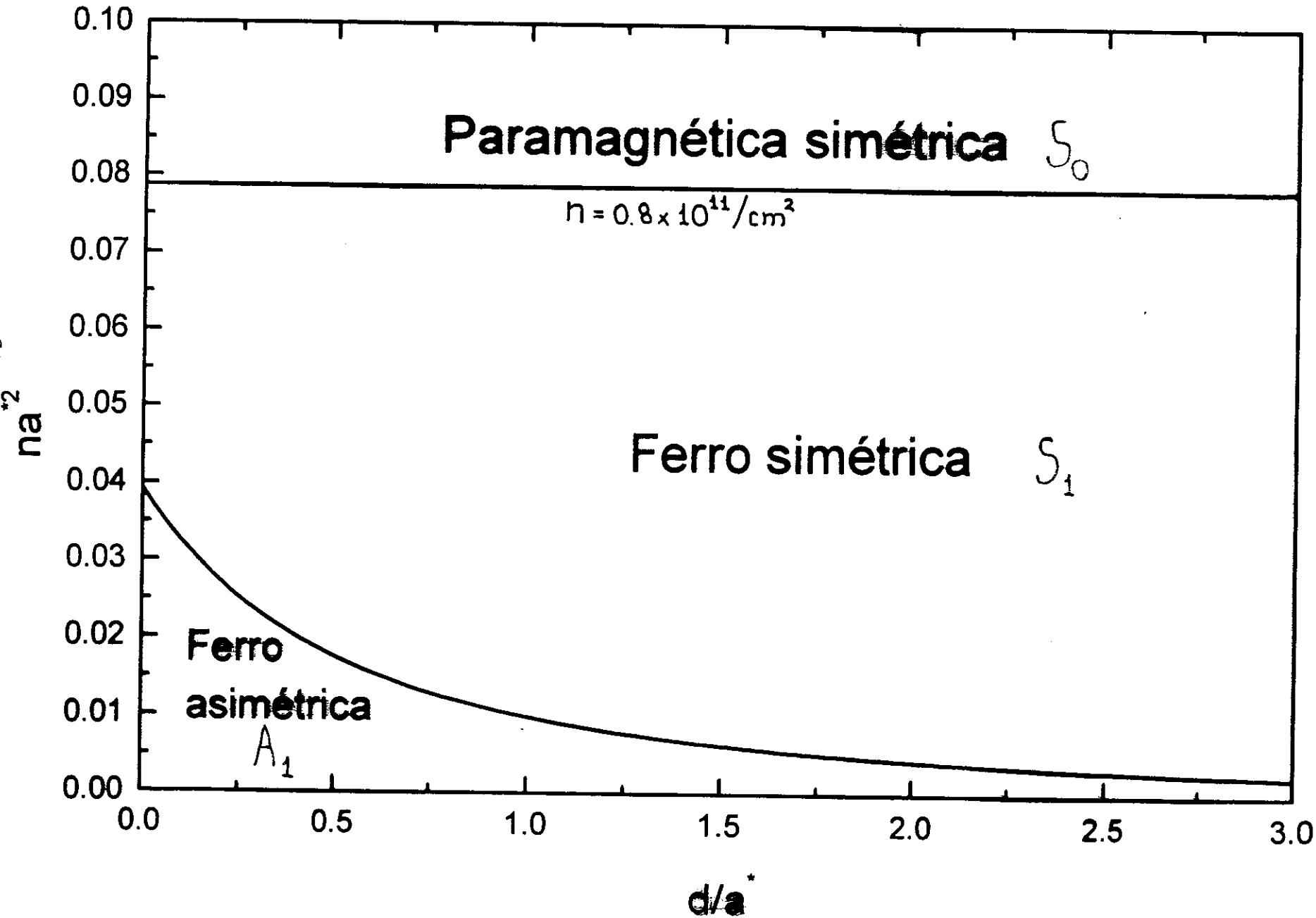
A) State S_0 $\quad n_1 = n_2 = n \quad m_1 = m_2 = 0$

B) State S_1 $\quad n_1 = n_2 = n \quad m_1 = \pm m_2 = 1$

C) State A_0 $\quad n_1 = 0, n_2 = 2n \quad m_1 = m_2 = 0$

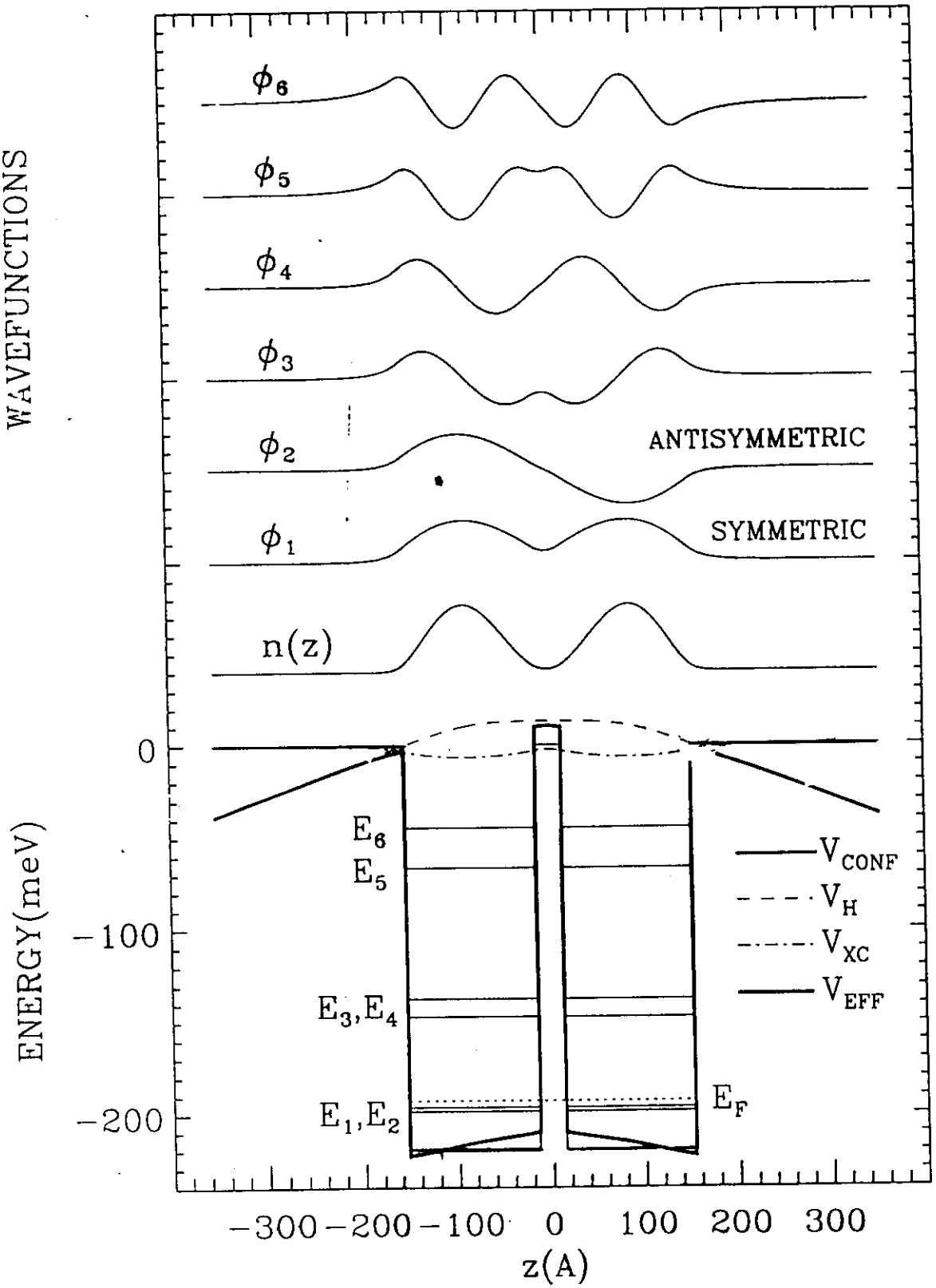
D) State A_1 $\quad n_1 = 0, n_2 = 2n \quad m_1 = 0, m_2 = \pm 1$

Bilayer (H-F approximation)

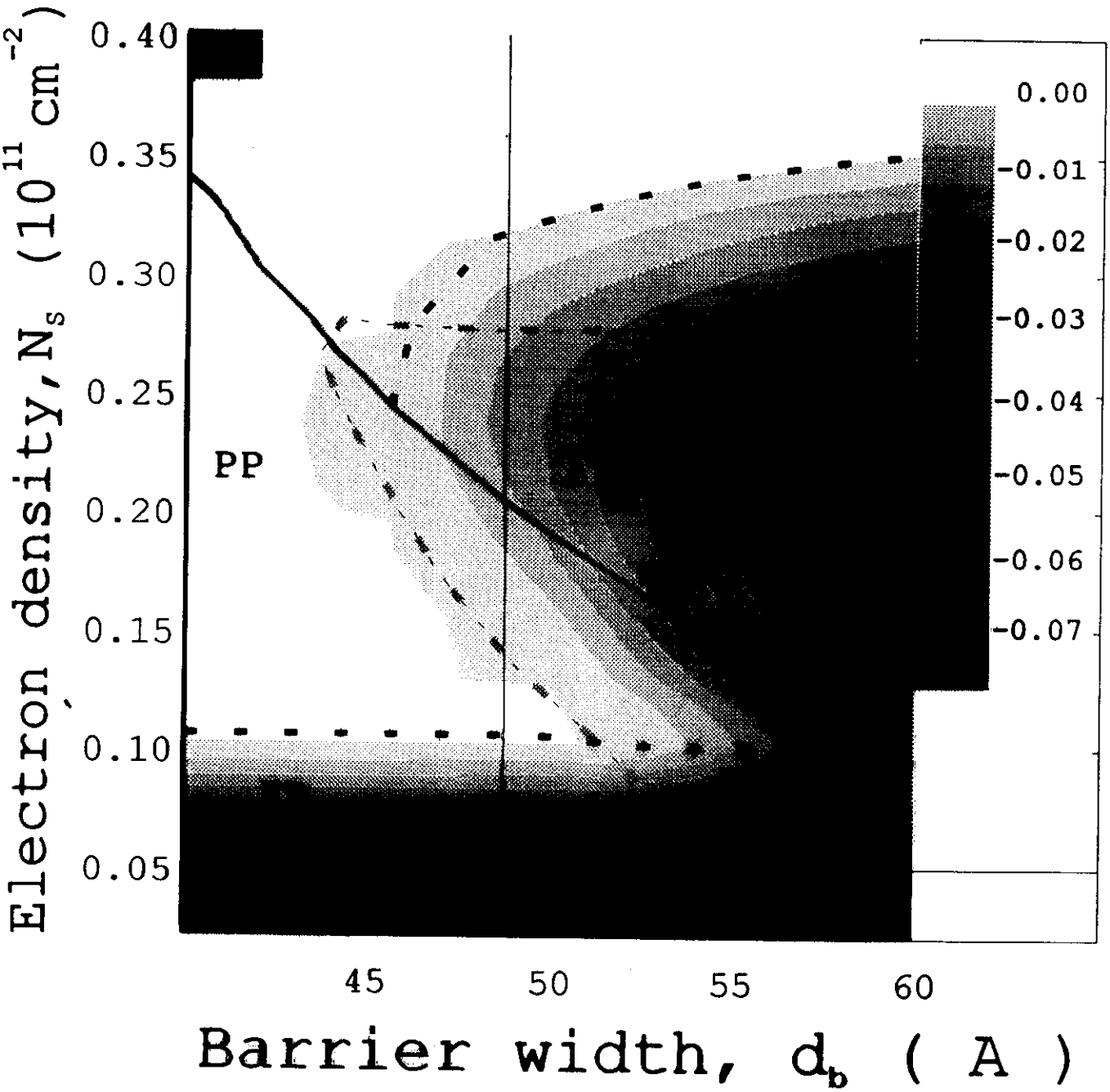


_SDA

Figure 1

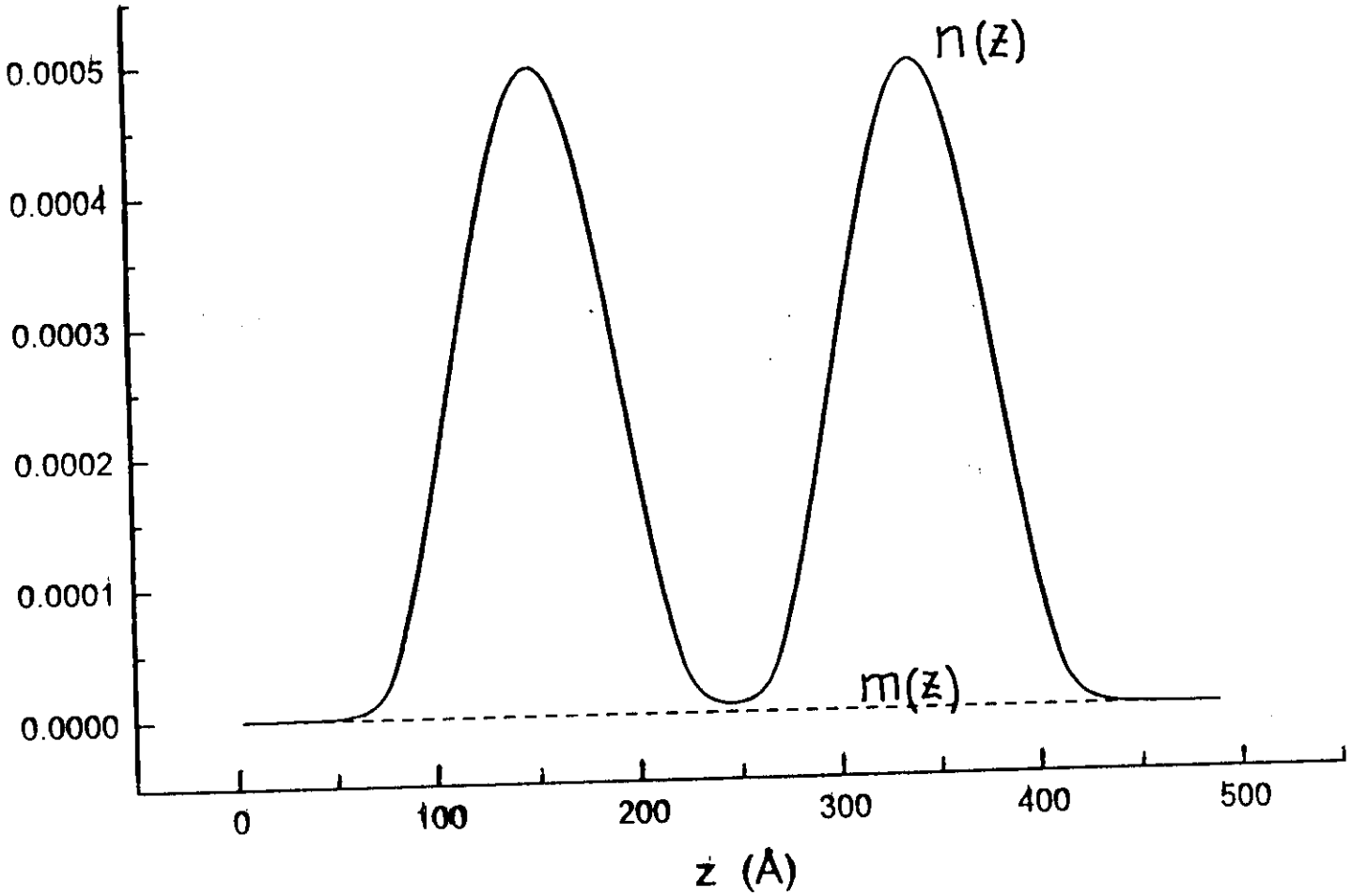


Reboredo and Proetto, PRL 79, 463 (97)



Reboredo and Proetto Figure 1

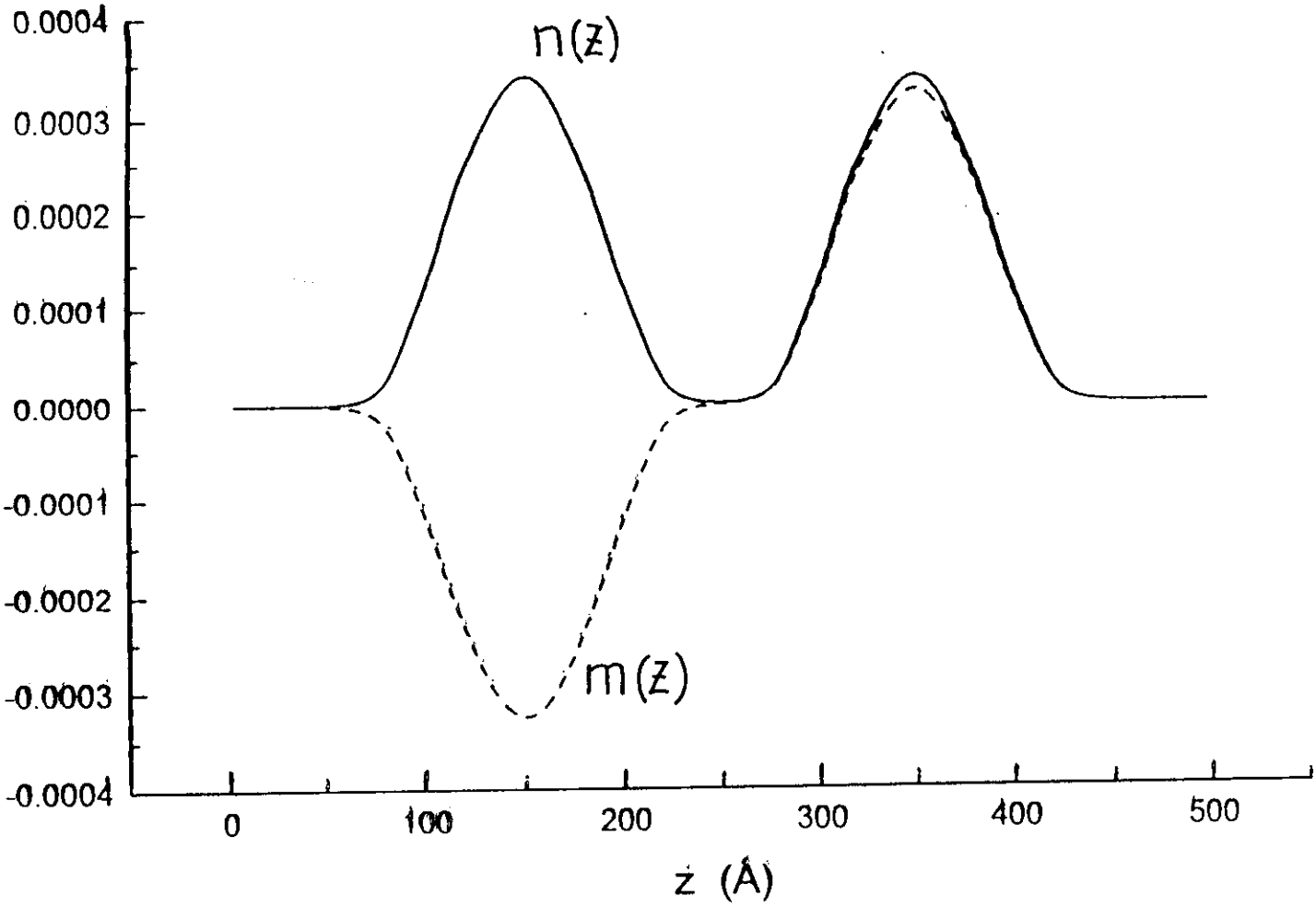
PP



$N_s = 0.36 \times 10^{11}/cm^2$

$d_b = 50$ Å

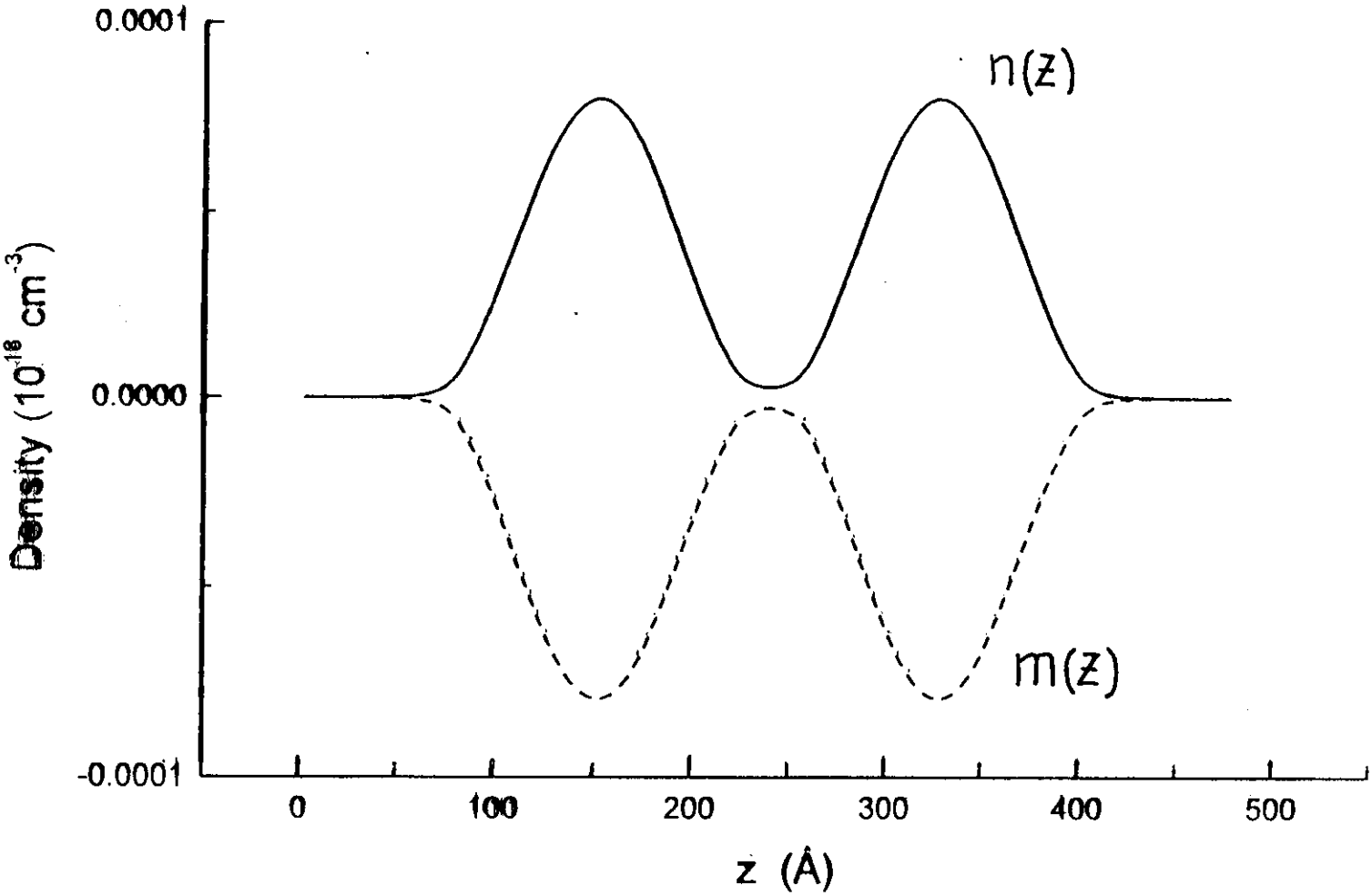
AP



$N_s = 0.24 \times 10^{11}/cm^2$

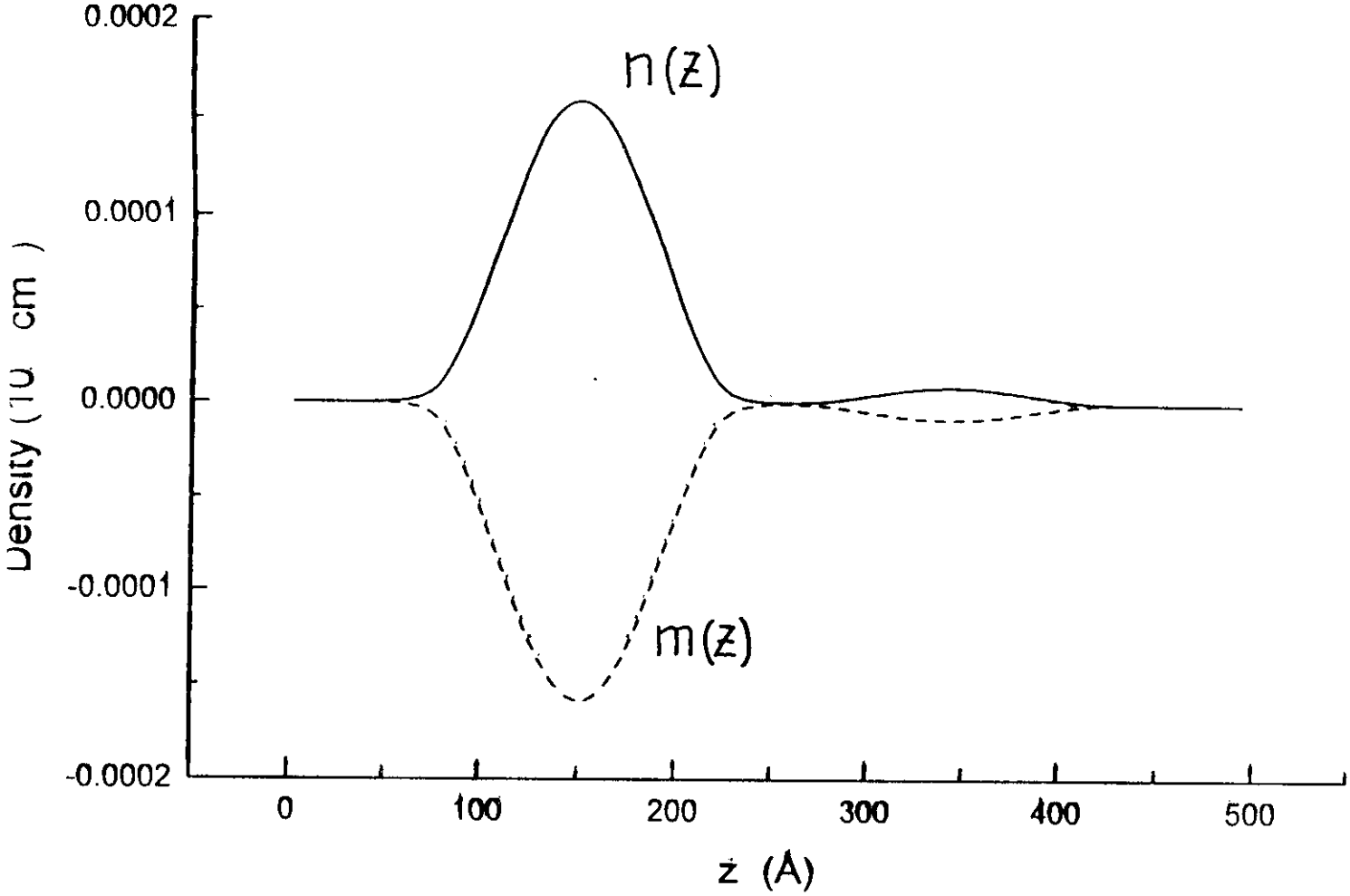
$d_b = 60$ Å

FP



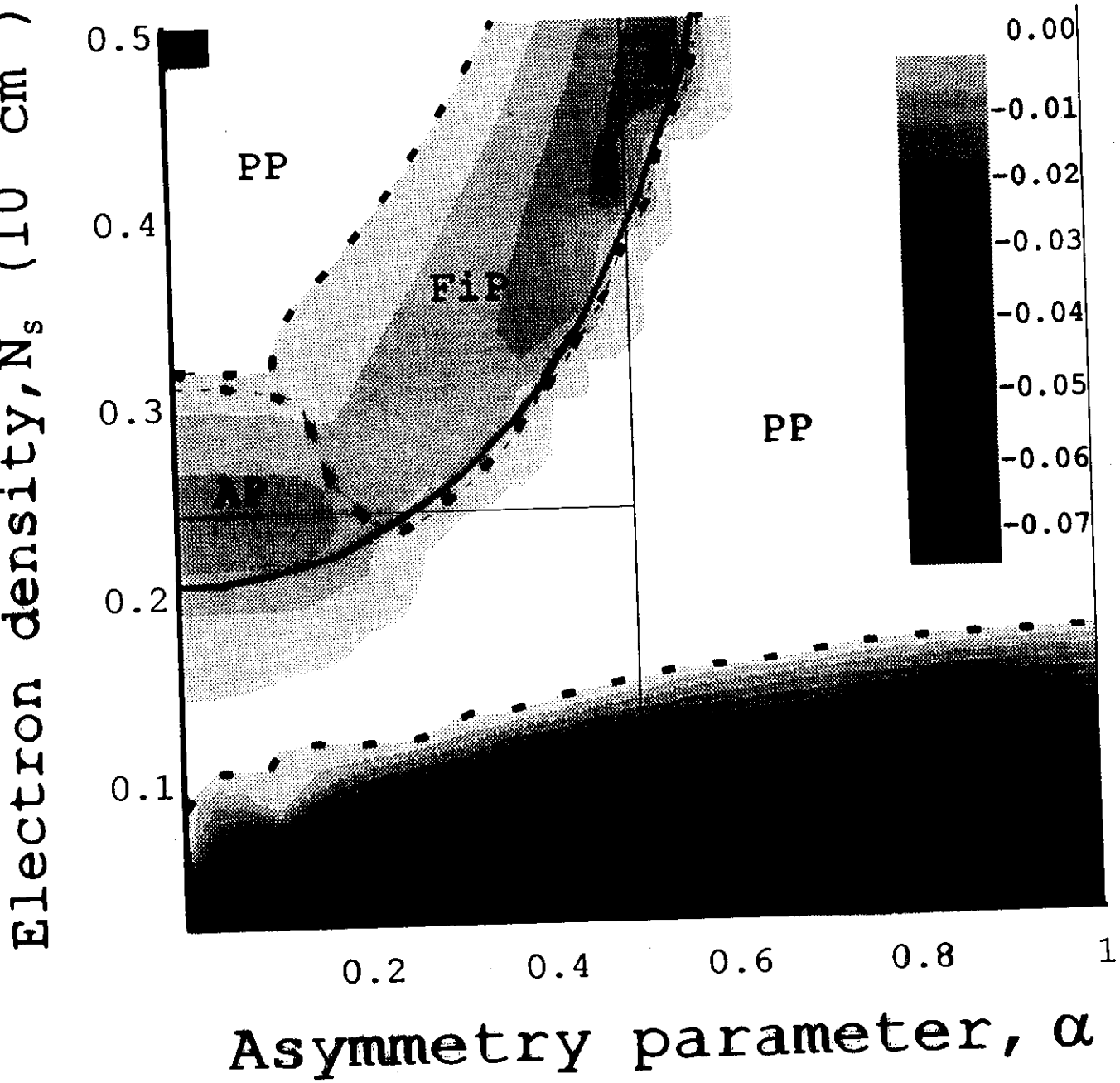
$N_s = 0.06 \times 10^{11}/cm^2$

$d_b = 40$ Å

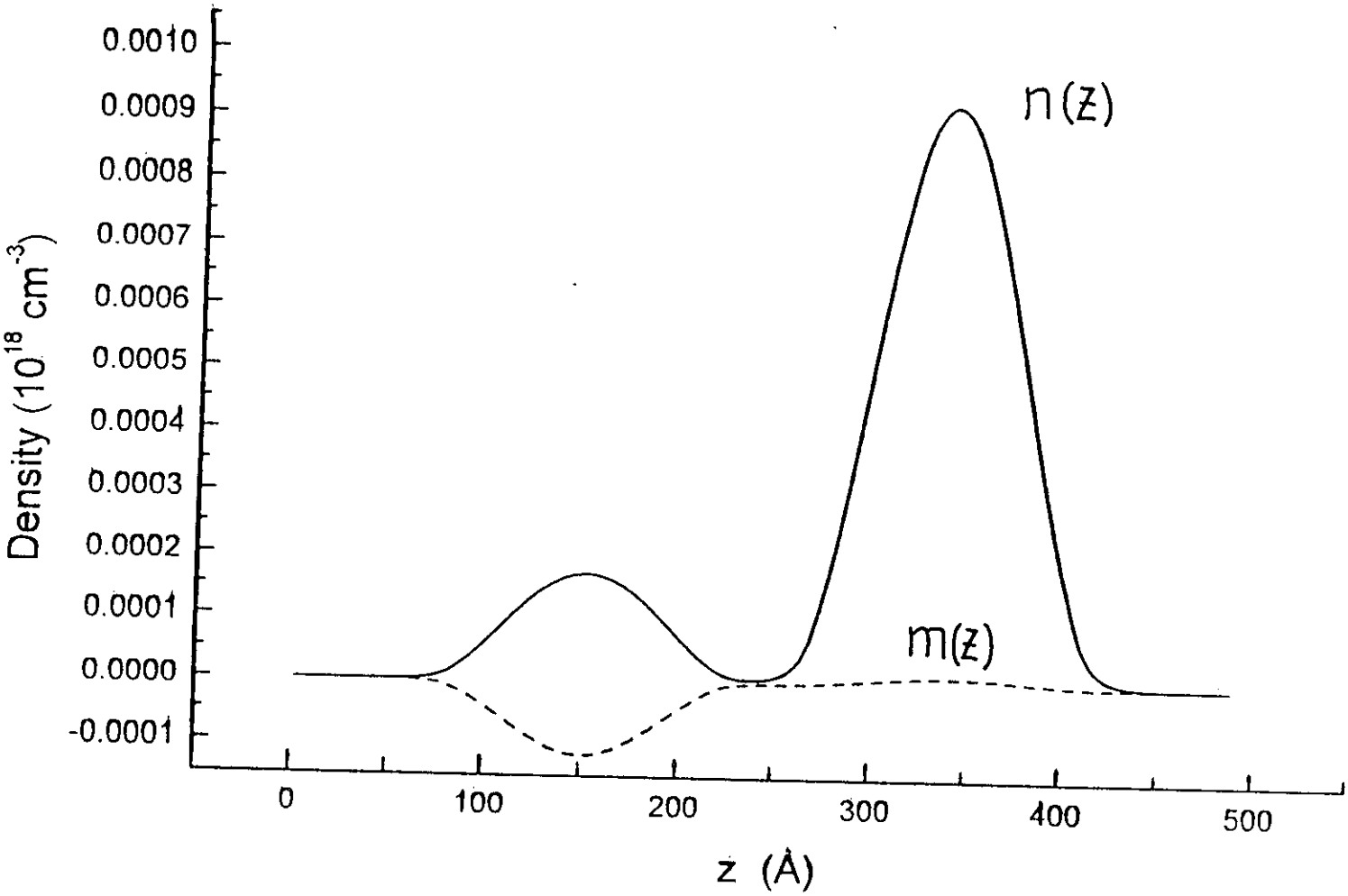


$N_s = 0.06 \times 10^{11}/cm^2$

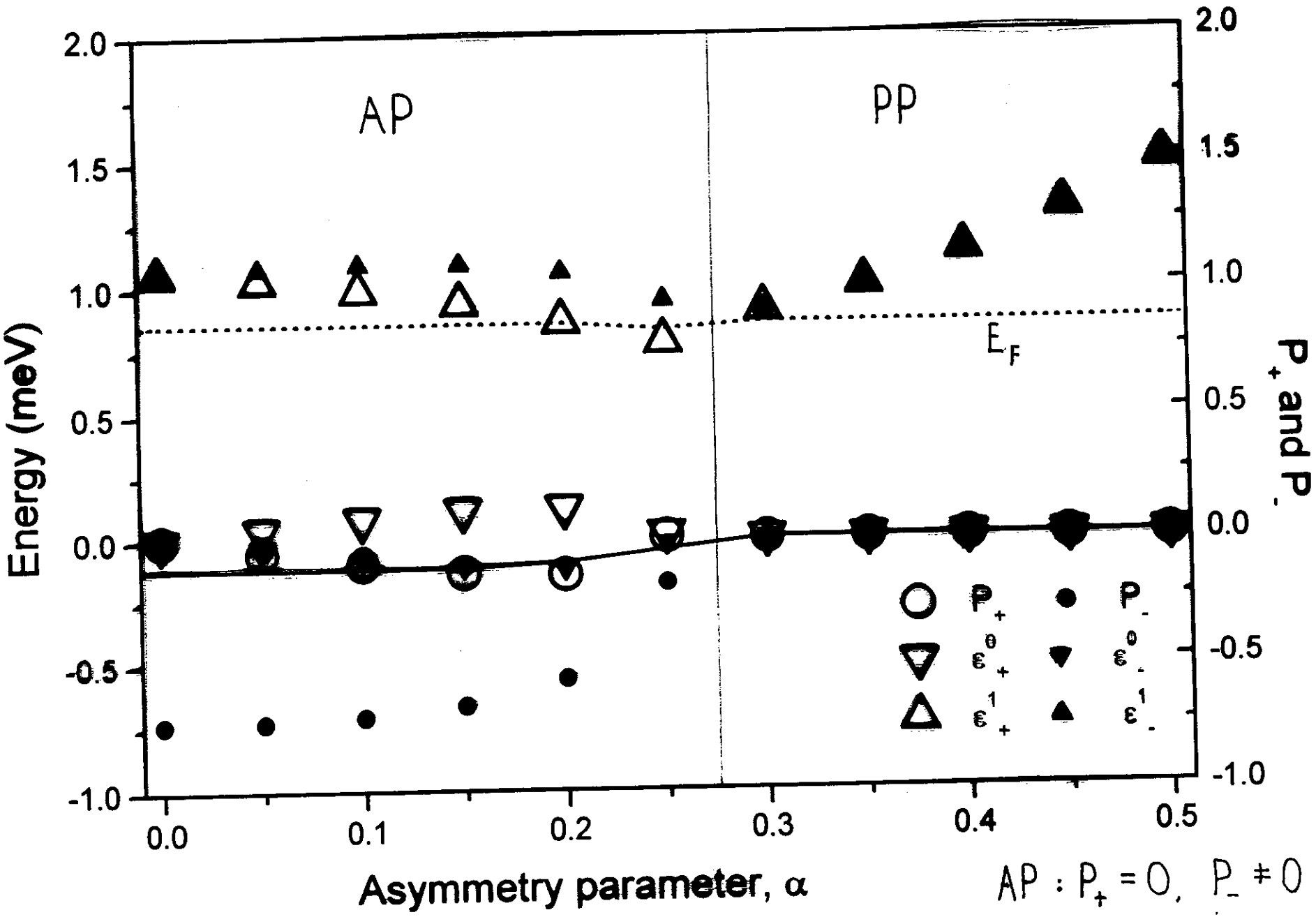
$d_b = 56$ Å


Electron density, N_s (10^{11} cm^{-2})
0.5
0.4
0.3
0.2
0.1
PP
FiP
AP
PP
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
0.2
0.4
0.6
0.8
1
Asymmetry parameter, α

FiP



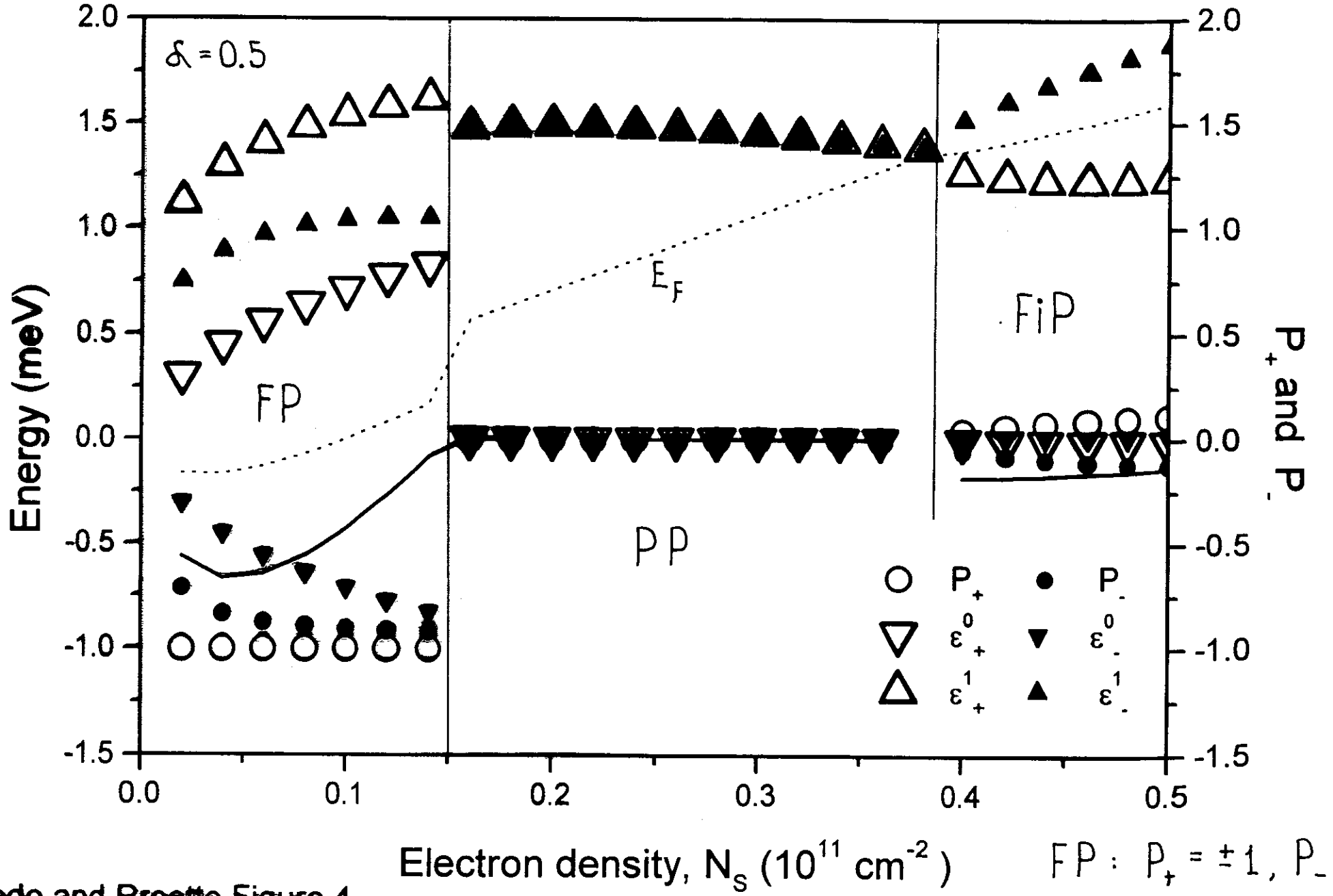
$N_s = 0.4 \times 10^{11}/cm^2$



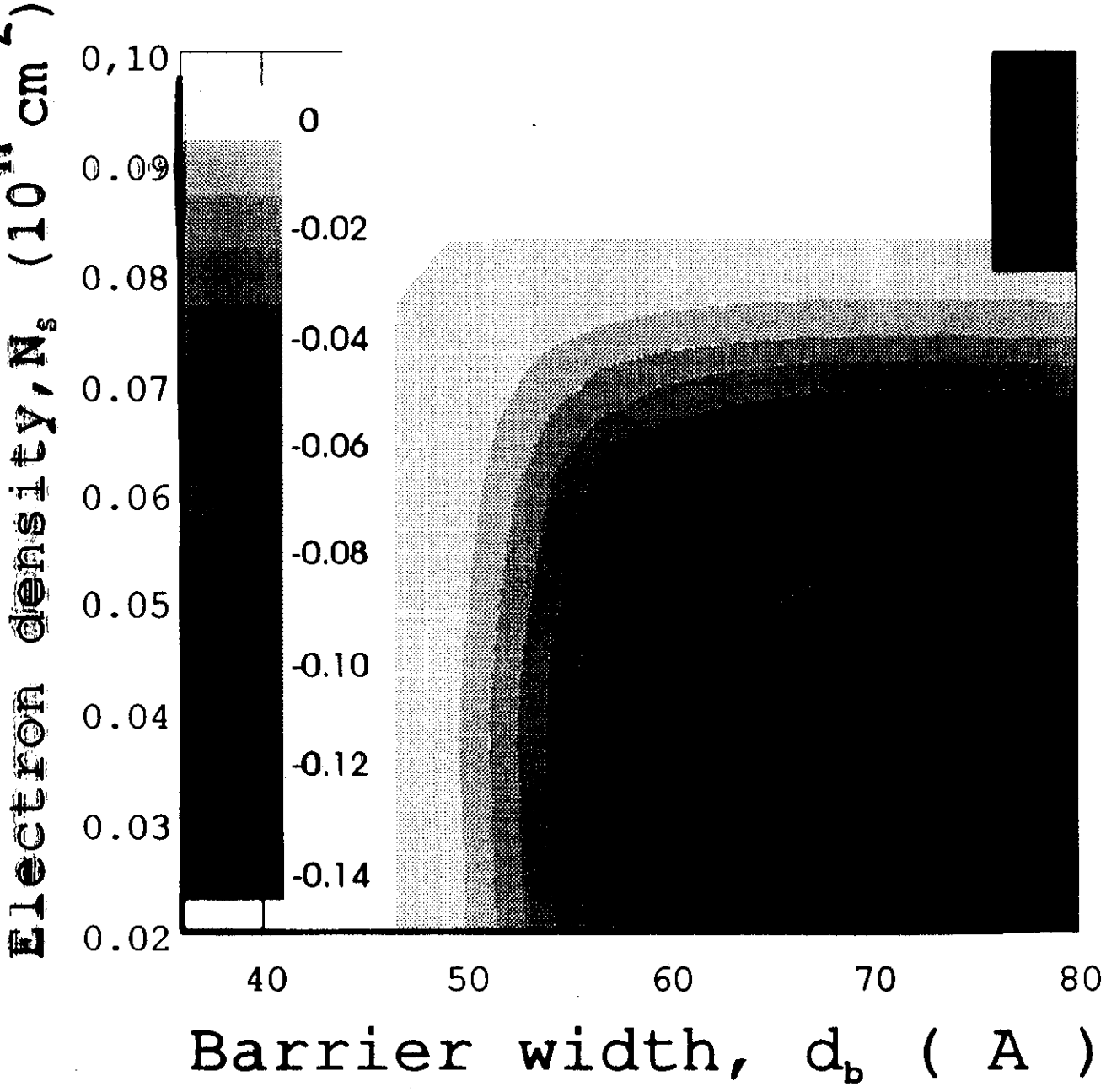
AP : $P_+ = 0$, $P_- \neq 0$

PP : $P_+ = P_- = 0$

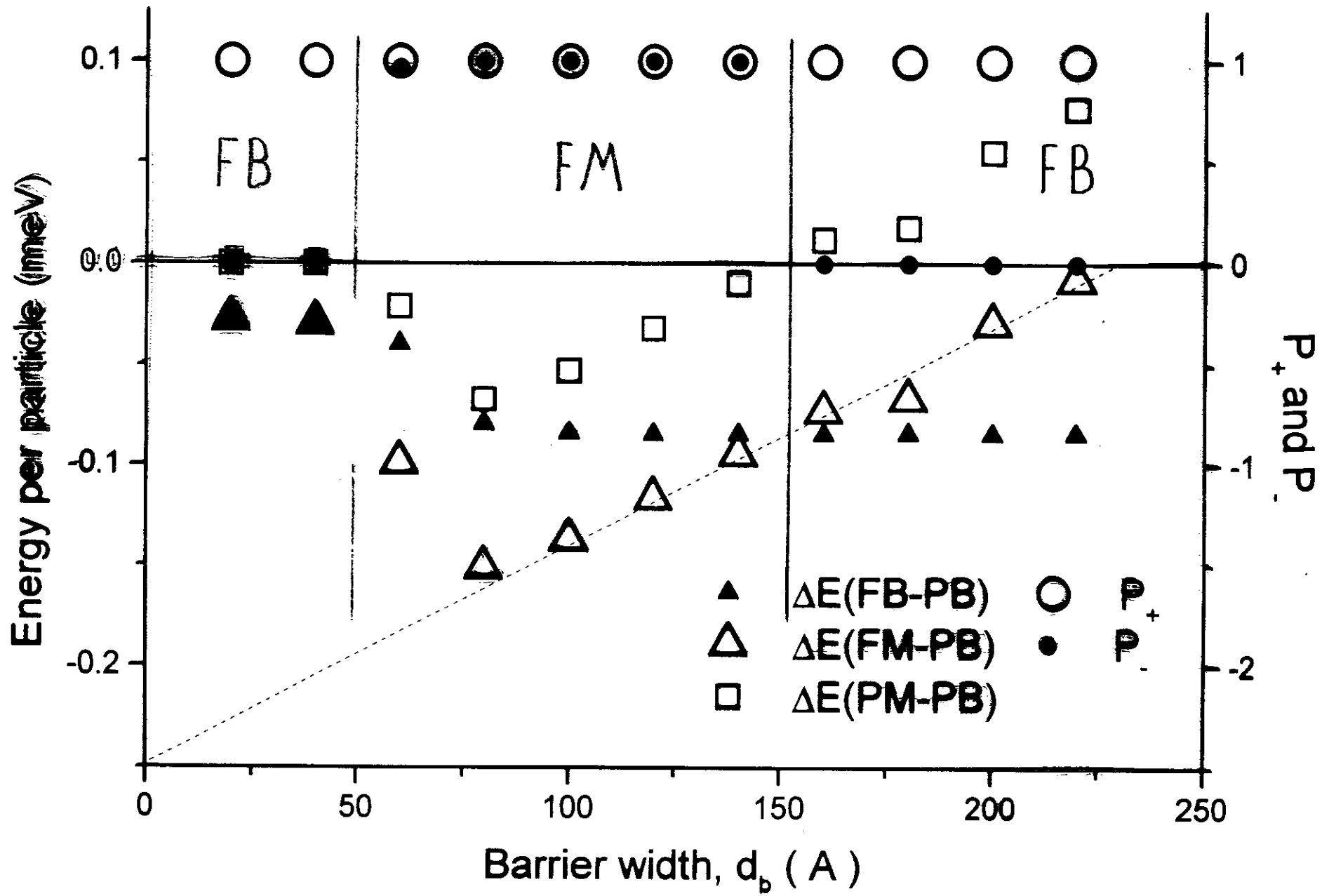
oredo and Proetto Figure 3



oredo and Proetto Figure 4



Reboredo and Proetto Figure 1



oredo and Proetto Figure 2