Casimir pressure
in MIS-structures
(metal-insulator-semiconductor)

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Quantum Field Theory Under The Influence Of External Conditions. 2011

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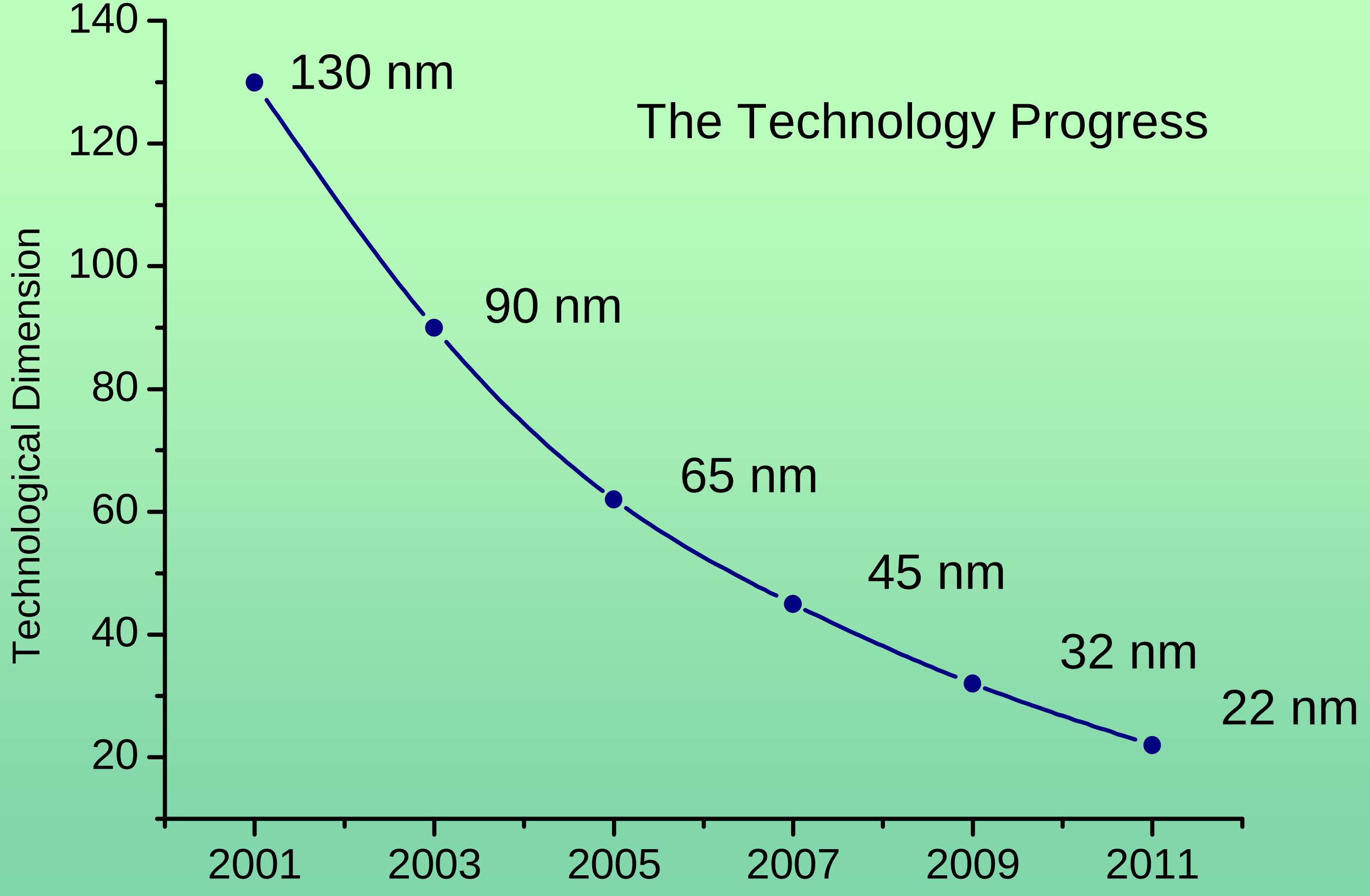
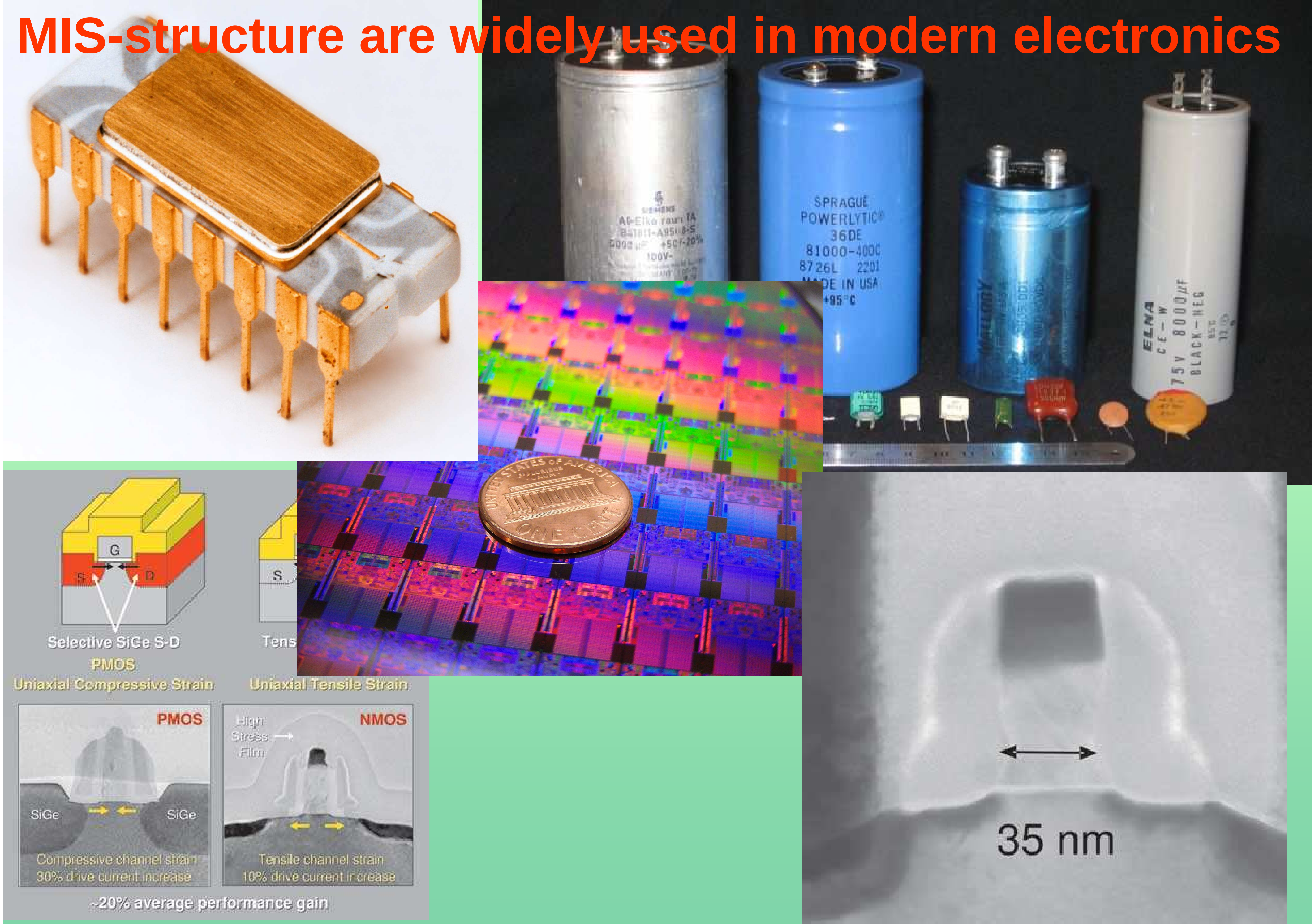
I Introduction.

Modern nanomechanisms and elements of microelectromechanical systems are made at micron and submicron levels. At these scales effects of quantum physics, including intermolecular interaction, become comparable with typical electric forces.



MIS-structure are widely used in modern electronics



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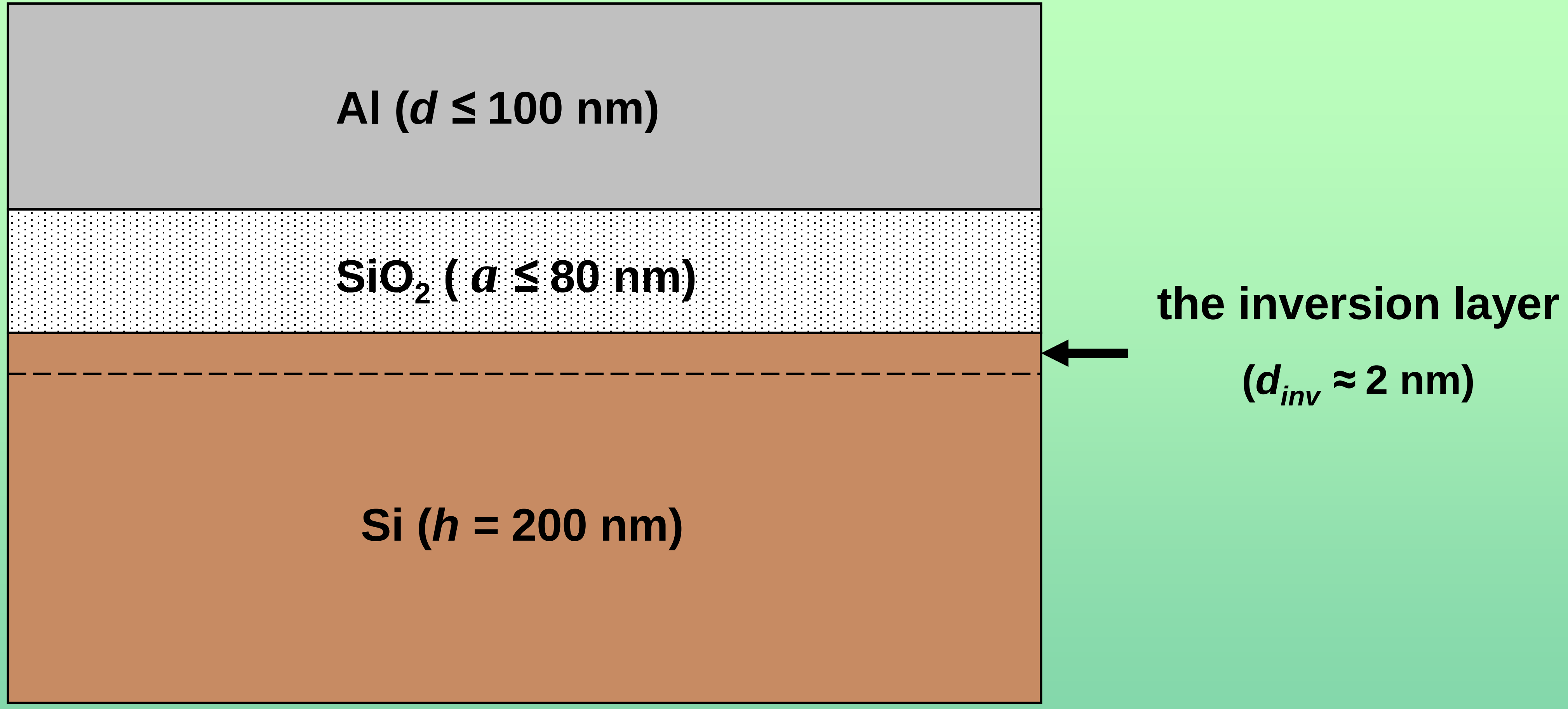
Typical MIS-structure is based on a Si single crystal and Al separeted with a thin layer of SiO_2.



Al ($d \leq 100$ nm)

SiO_2 ($a \leq 80$ nm)

Si ($h = 200$ nm)

the inversion layer

($d_{inv} \approx 2$ nm)

The aims of the research:

- to determine the Casimir pressure on the insulating layer in the MIS-structure based on a silicon substrate;
- to estimate the influence of the insulator thickness and creation of the inversion layer on the Casimir pressure.

It is the first research of the Casimir pressure in real MIS-structure, widely used in modern electronics.

II The major aspects of Lifshitz theory.

According to the Lifshitz theory the general formula for the Casimir pressure between two material layers separated with gap of width a in thermal equilibrium at temperature T:

$$P(a,T) = -\frac{k_B T}{\pi}\sum_{l=0}^{\infty}\left(1-\frac{\delta_{l0}}{2}\right)\int_0^{\infty} k_\perp dk_\perp K_l^{(0)}$$

$$\times\sum_q\left[\frac{e^{2K_l^{(0)}a}}{r_q^{(0,1)}(i\xi_l,k_\perp)\,r_q^{(0,2)}(i\xi_l,k_\perp)}-1\right]^{-1}$$

where the notations are used:

k_B is the Boltzmann constant;

q is the TM and TE modes of the electromagnetic field;

δ_{l0} is the Kronecker symbol;

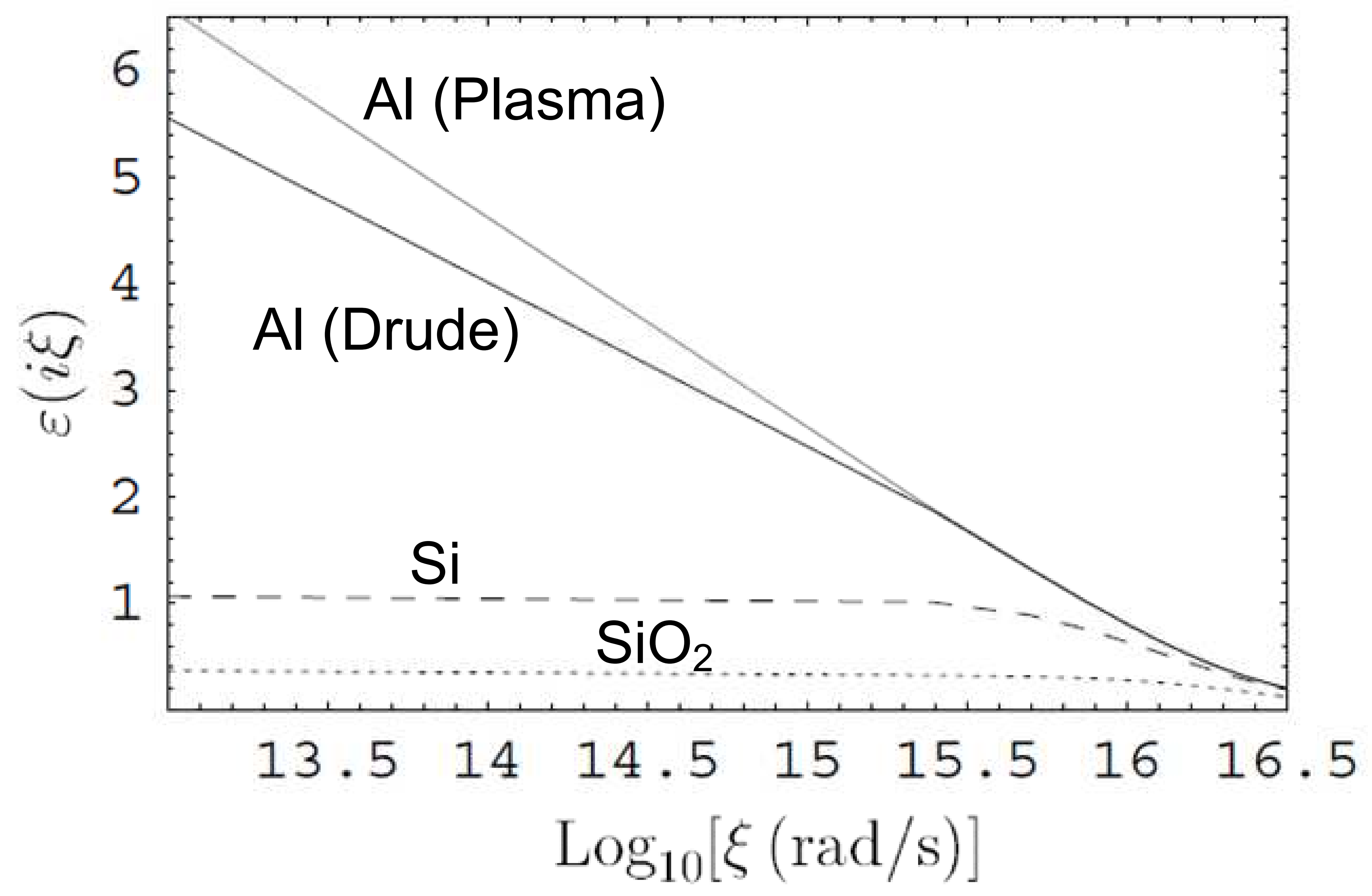
$k_\perp$ is the magnitude of the projection of the electromagnetic wave vector onto the plane of plates;

$\xi_l = 2\pi k_B T l / \hbar \left(l = 0,1,2\ldots \right)$ are the Matsubara frequencies;

r_q are the Fresnel reflection coefficients for two polarizations of the electromagnetic wave;

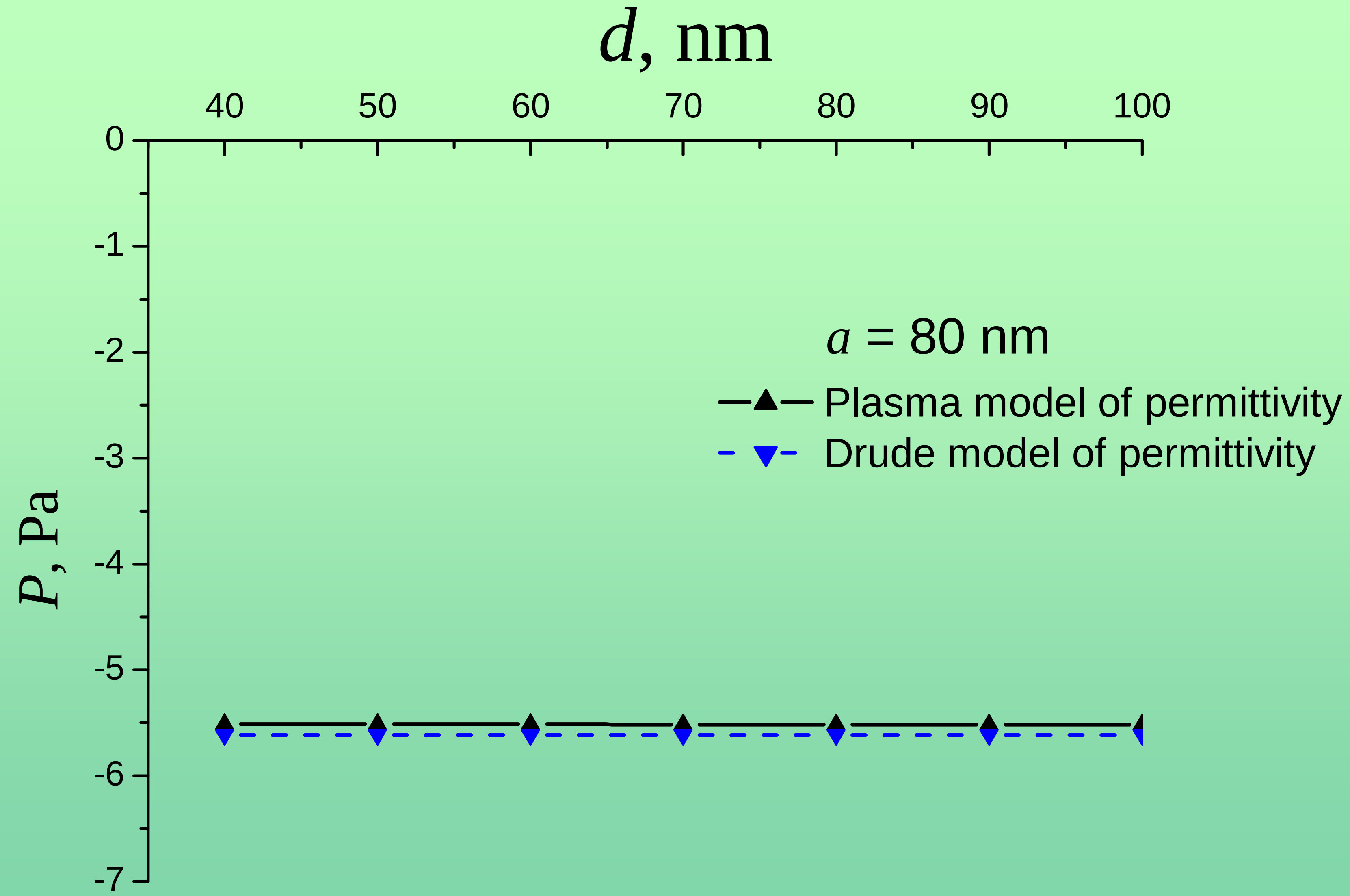
$$K_l^{(n)} \equiv \sqrt{k_\perp^2 + \varepsilon_l^{(n)} \frac{\xi_l^2}{c^2}}.$$

Dielectric permittivities used

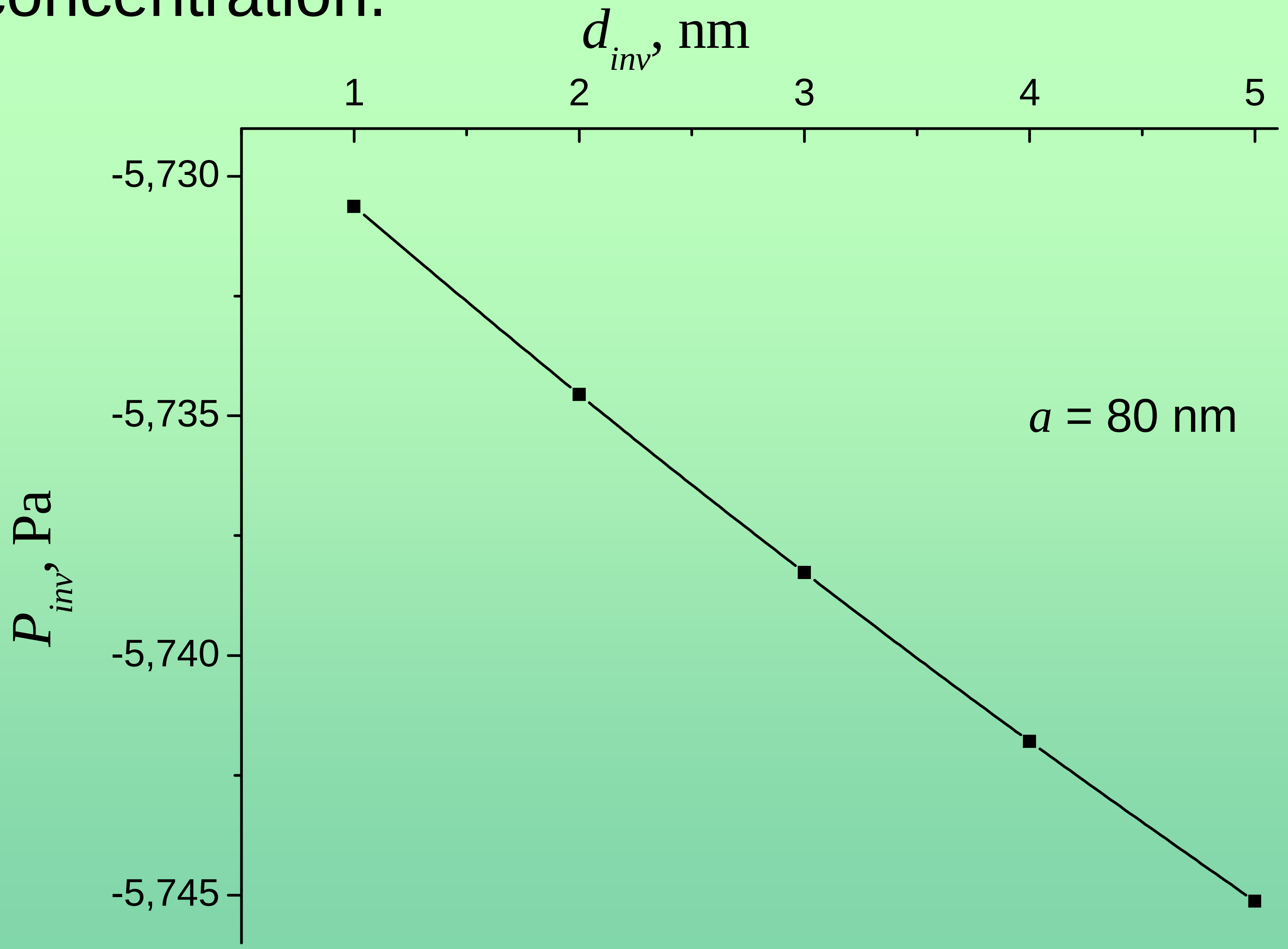


III Calculation results.

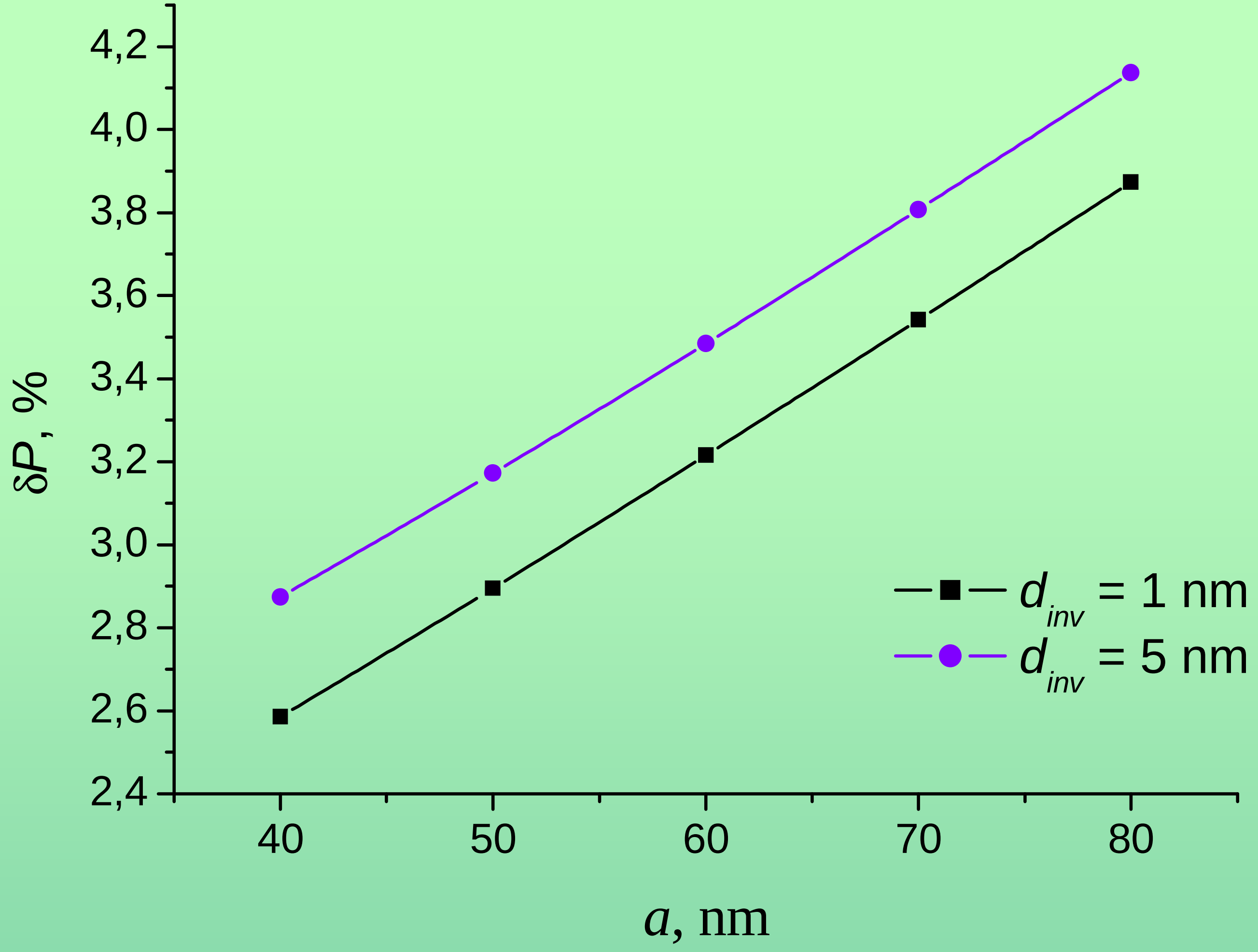
1. The Casimir pressure in MIS-structure is almost independent on the thickness of aluminum layer.



2. Calculated dependence of the Casimir pressure on the thickness of the layer with increased carrier concentration.



The Casimir pressure slightly depends on the thickness of inversion layer in the MIS-structure for any thickness of an isolator layer.



The relative increase δ*P* in the pressure on the insulating layer is only 3.9% and 4.15% for a layer thicknesses of 1 and 5 nm, respectively.

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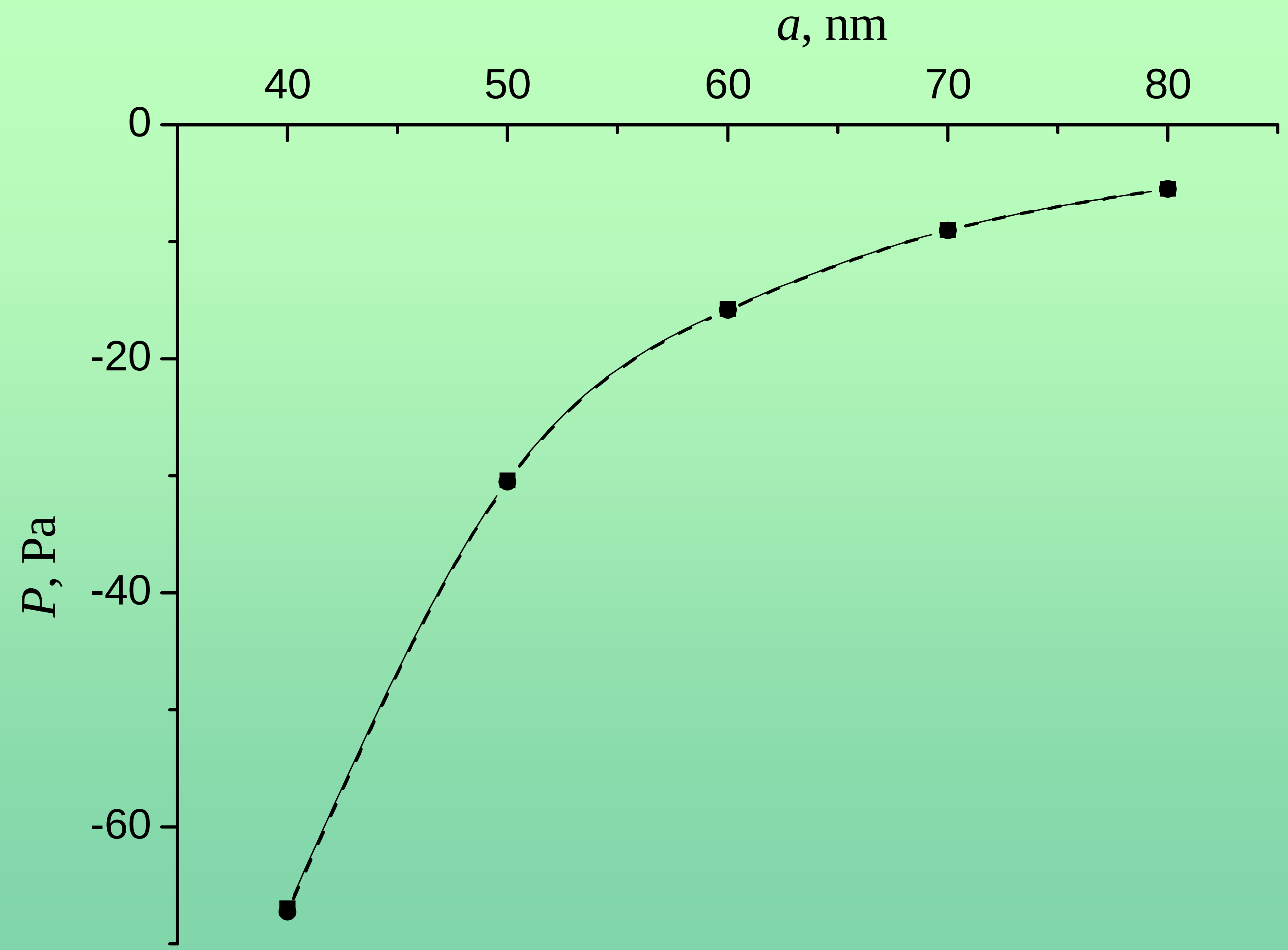
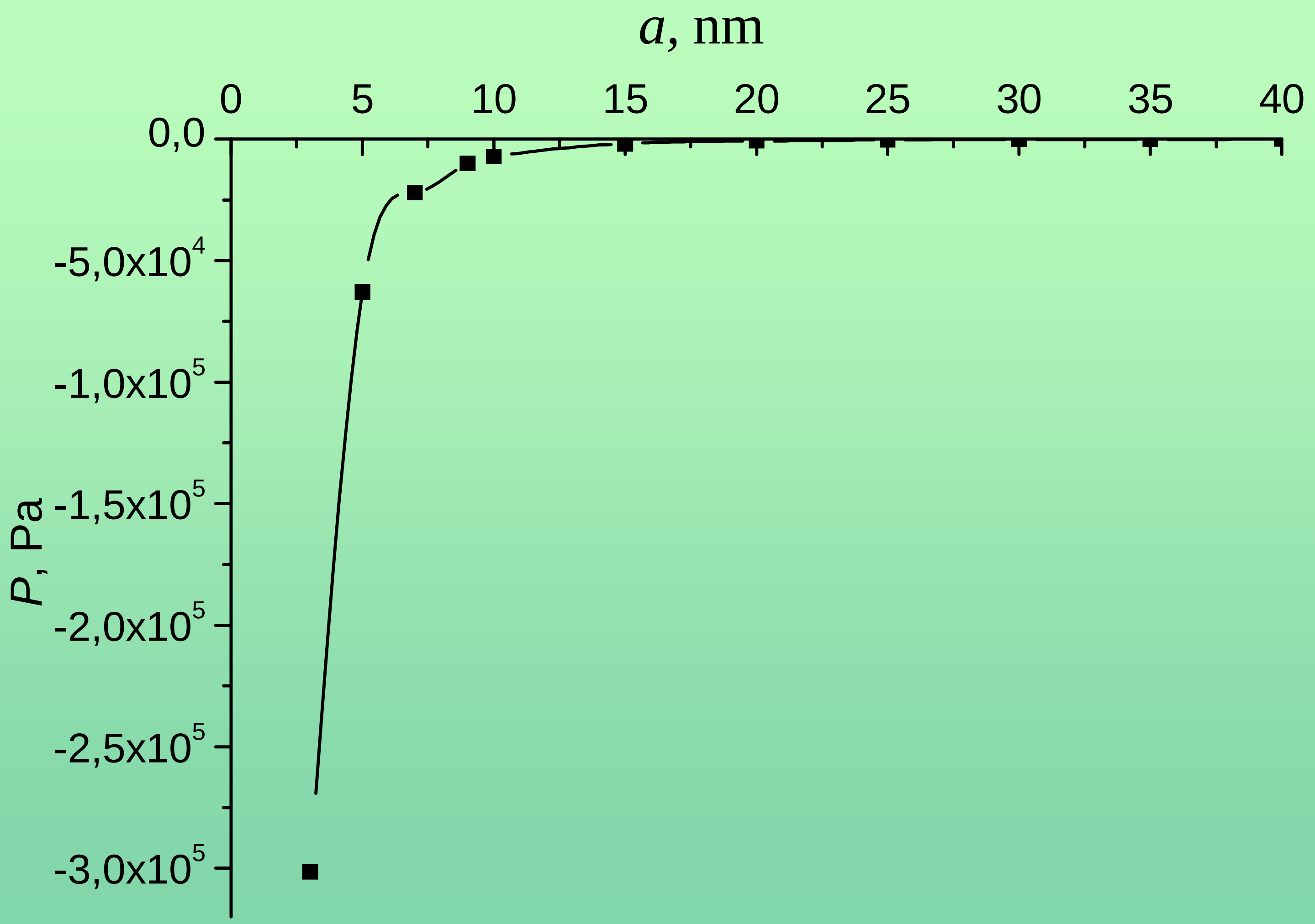
3. The Casimir pressure strongly depends on the SiO_2 layer thickness: when *a* <u>decreases</u> from 80 to 40 nm, the pressure *P* <u>increases</u> from 5 Pa to almost 70 Pa.



4. Further decrease of the SiO_2 layer thickness leads to the increase of the value of the Casimir pressure by several orders of magnitude.

At a = 3 nm the Casimir pressure is $P = 3.01\times10^5$ Pa.



1 nm is about 3 – 5 atomic layers.

In this case we have to take into account the atomic structure of materials to describe permittivities and calculate the value of Casimir pressure in MIS-structure with isolator’s thickness $a \leq 3$ nm.

It is the subject for our future research.

IV Nonrelativistic limit.

As the distance between conducting layers can be less than the characteristic wavelength of the absorption spectrum, we calculate the Casimir pressure in the nonrelativistic limit.

The Casimir pressure in the nonrelativistic limit:

$$P(a) = -\frac{H}{6\pi a^3}$$

H is the Hamaker constant:

$$H = \frac{3\hbar}{\pi}\int_0^\infty d\xi \int_0^\infty y^2 dy \left[\frac{e^y}{r_{Al}\cdot r_{Si}} - 1\right]^{-1}$$

For our MIS-structure the Hamaker constant is:

$H = 1.61\times10^{-19}$ J,

(the Drude model of aluminum permittivity).

at $a = 3$ nm P = -3.16×10^{5} Pa

$H = 1.60\times10^{-19}$ J,

(the plasma model of aluminum permittivity).

at $a = 3$ nm P = -3.14×10^{5} Pa

So the result of calculation is independent of the model used to describe the aluminum permittivity.

The values of the Casimir pressure are similar: in the relativistic limit at $a = 3$ nm $P = 3.01\times10^{5}$ Pa.

V Conclusions:

- The Casimir pressure is investigated in MIS-structure, based on a silicon substrate.
- The Casimir pressure increases from 5 Pa to almost 10^5 Pa, if the thickness of the isolator layer decreases from 80 nm to 3 nm.
- The inversion layer with high charge concentration only slightly effects the value of the Casimir pressure.
- This value does not depend on the thickness of a metal layer and the model of its permittivity.

Thanks for attention