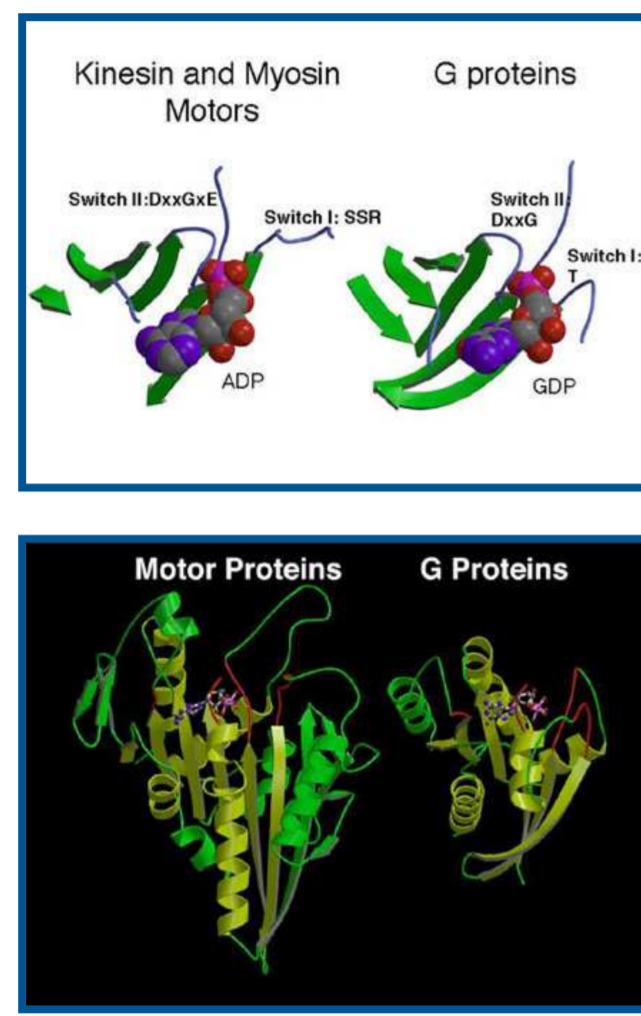


## Abstract

The directed electron transport in the spatially-periodic asymmetrical system – called “ratchet” – is under study. It is a system of two-dimensional electrons (2DES) formed in the semiconductor heterojunction and driven by the external linear-polarized microwave irradiation. The spatial inversion symmetry of the system is broken by introducing of artificial periodic array of asymmetric antidots shaped in semi-disk form. The directed electric current of few  $\mu\text{A}$  has been observed under the microwave irradiation. Polarization experiments show that this current is determined by symmetry of the antidot array, that's accord to the theoretical predictions. The effect proved to be quite rigid and uniform, having no dependence on material, but on geometry of the system only.

## The theory...

**Microscopic motors?**  
They are well known for microbiologists!

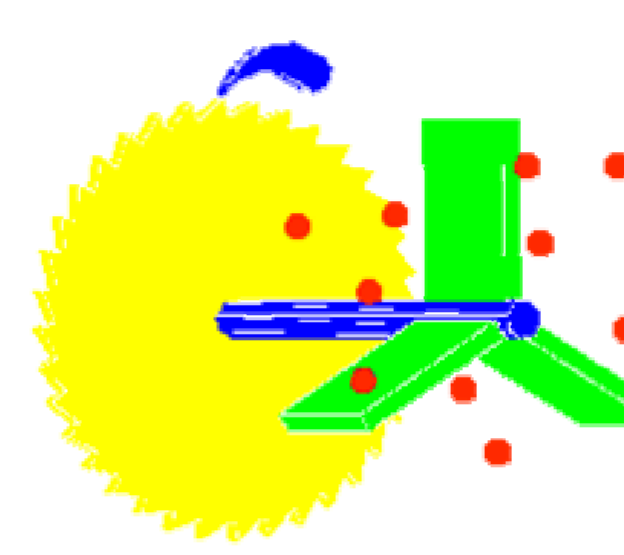


**Protein motors**, perfected over the course of millions of years by evolution, work in every cell of our bodies! They drive the directed motion in the face of inescapable thermal and other noise.

**Why does protein motor work?**  
Because of broken symmetry!

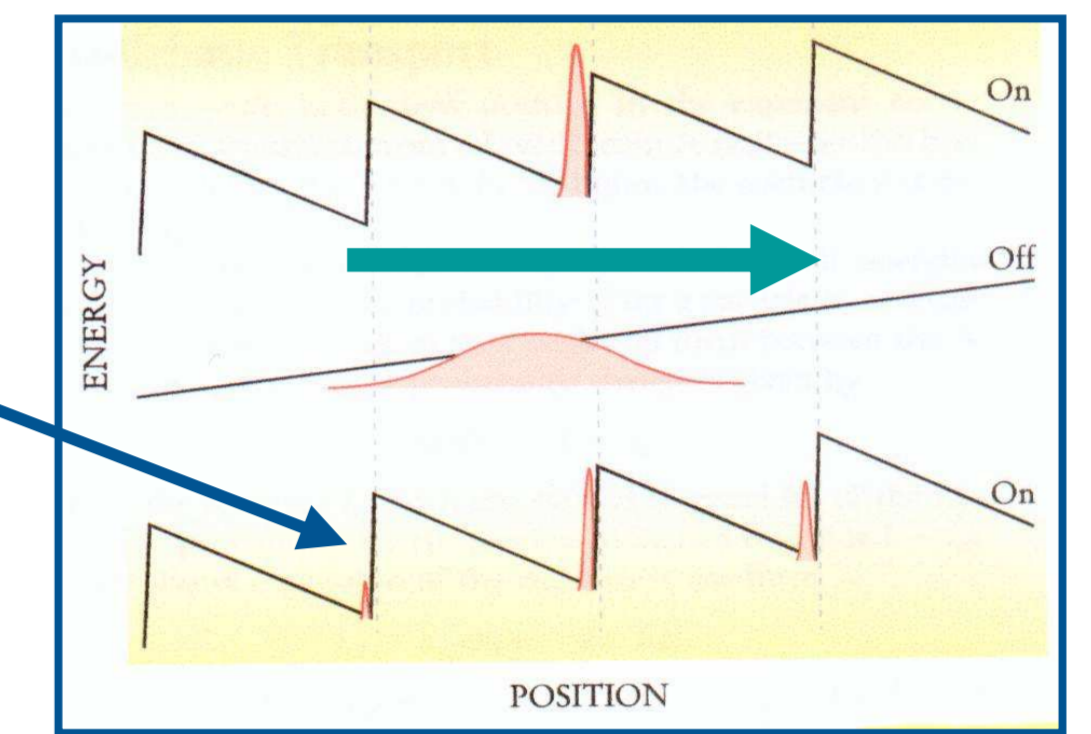


**How does these microscopic motors work?**  
There could be a lot of different “constructions”, but the main principle is always the same: in systems with broken symmetry the noise itself (thermal noise, etc) assists to the directed motion, providing a mechanism for overcoming the energy barriers.



**How to get the control upon directed motion in the ratchet?**

saw-tooth potential is a “fuel”  
particle is a “motor”

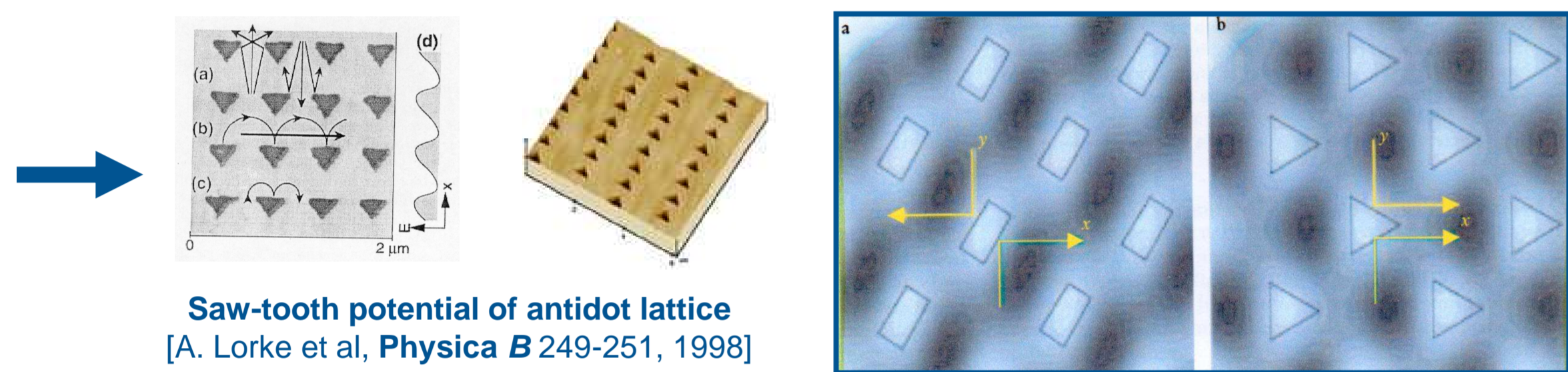


Such systems have received the name “Brownian motors” or “ratchets”.

Two main ingredients are: **symmetry breaking** and **energy input**.

**Two-dimensional mesoscopic ratchet on heterostructure.**

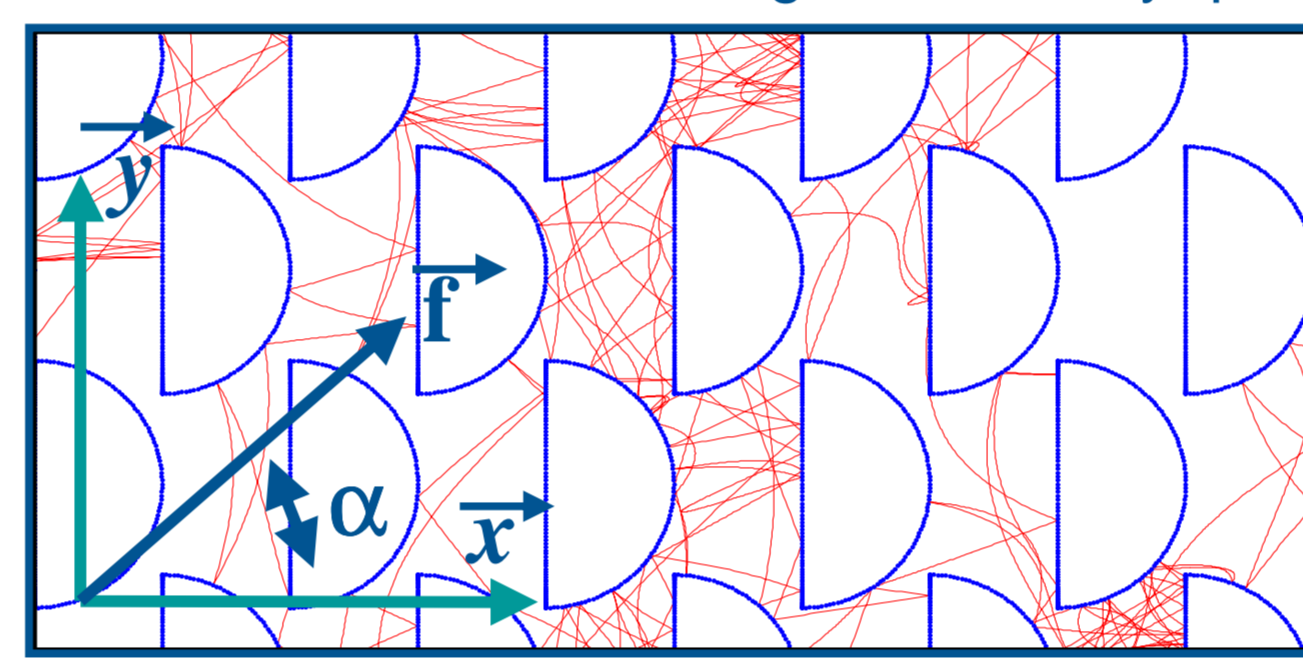
The mesoscopic periodical system of scattering centres — array of quantum asymmetric antidots — can be realised within 2DEG at the main interface in semiconductor heterojunction.



Saw-tooth potential of antidot lattice  
[A. Lorke et al, Physica B 249-251, 1998]

Exposed to the linear-polarised microwave irradiation asymmetric antidot lattice will play a role of **quantum ratchet**, while the microwaves itself will serve as driving force and at the same time as external energy input.

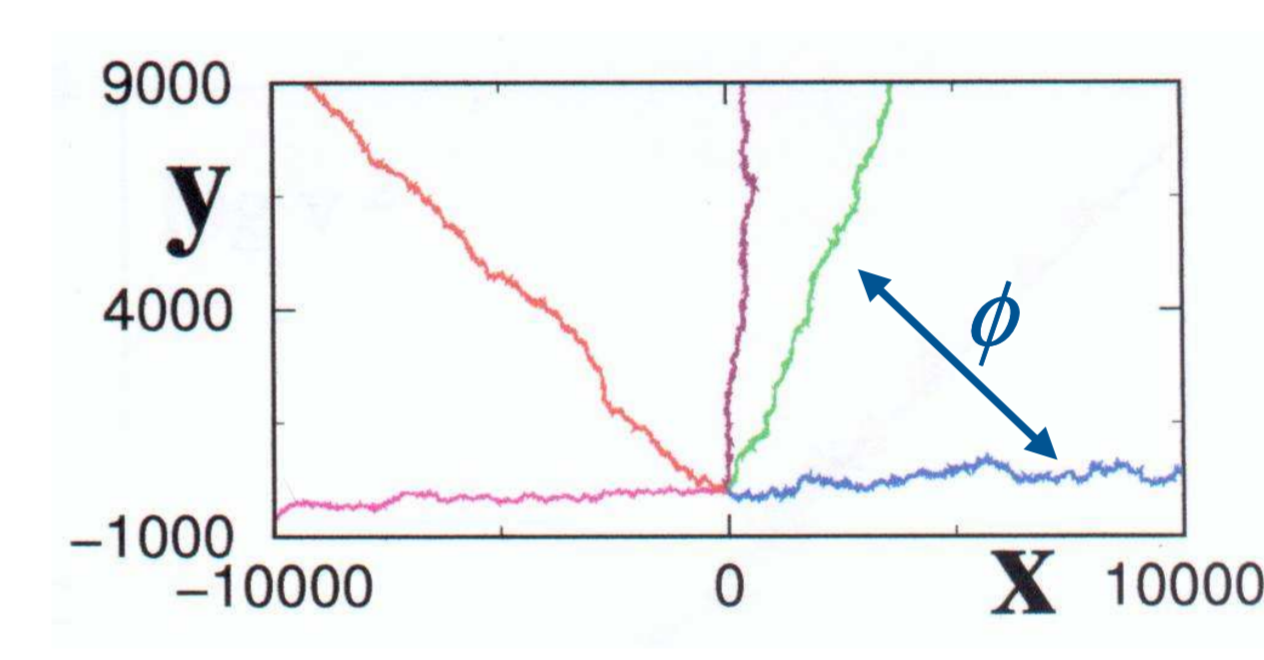
[A.D. Shepelyansky and D.L. Shepelyansky (Phys. Rev. B 71, 052508, 2005)] “Changing the linear polarisation of monochromatic microwave radiation in presented ratchet it is possible to change the direction of transport. The system could exhibit even the “negative mobility” phenomenon...”



Modified “Galton board” – triangular lattice of rigid semidisks.

$$\vec{T} = f(\cos \alpha, \sin \alpha) * \cos \omega t + \dots$$

... + “friction”



Directed transport for one trajectory at various polarizations of radiation:  $\phi = 0, \pi/8, 0,21\pi, \pi/8, \pi/2$  (from left to right clockwise)

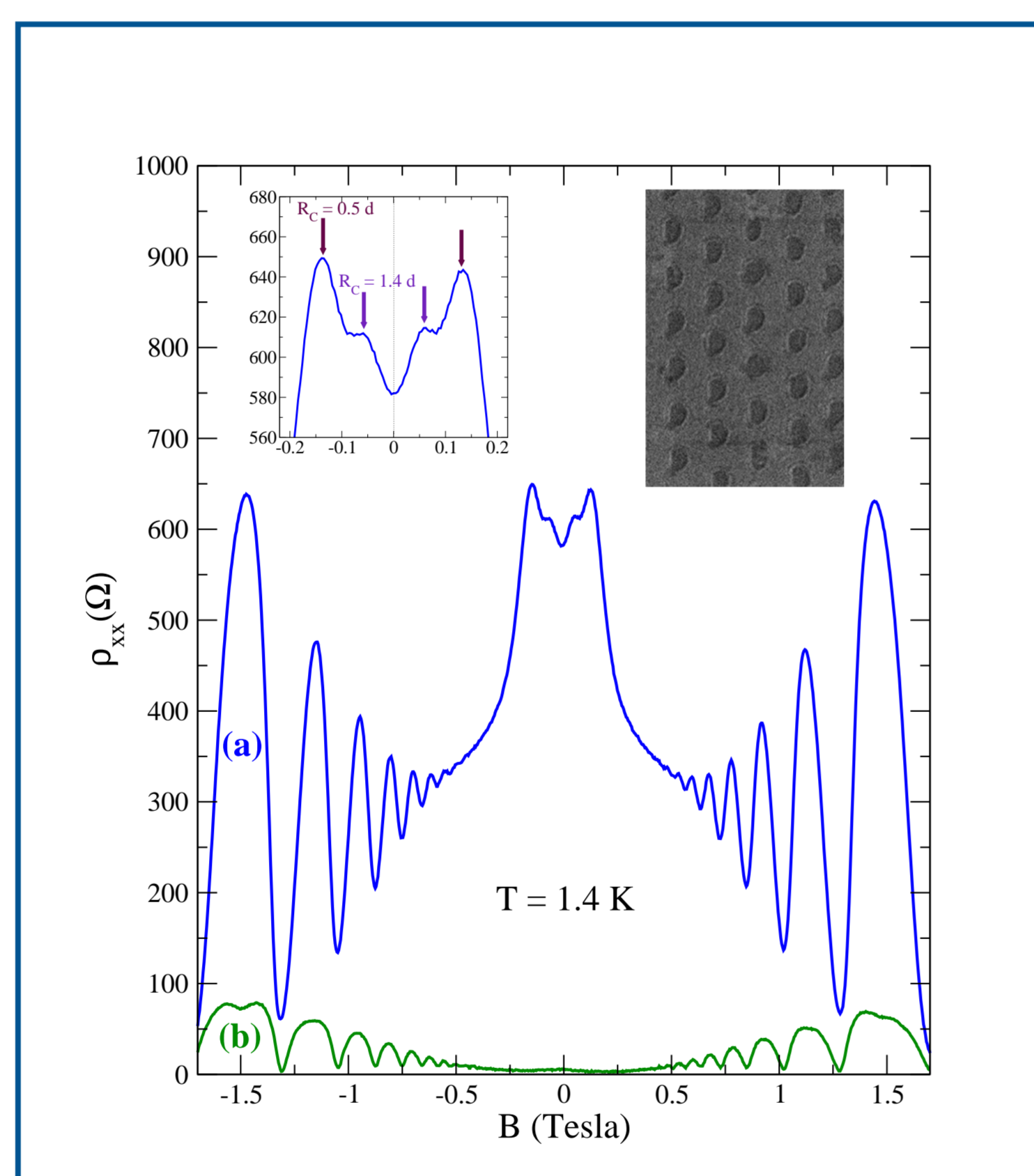
average velocity:  $\vec{v}_f = v_f(\cos \phi, \sin \phi)$

“...directed transport induced by polarized radiation is **robust phenomenon** which is not very sensitive to the parameters of the model... it's direction linked to a strange attractor...”

So...

## ... and the experiment

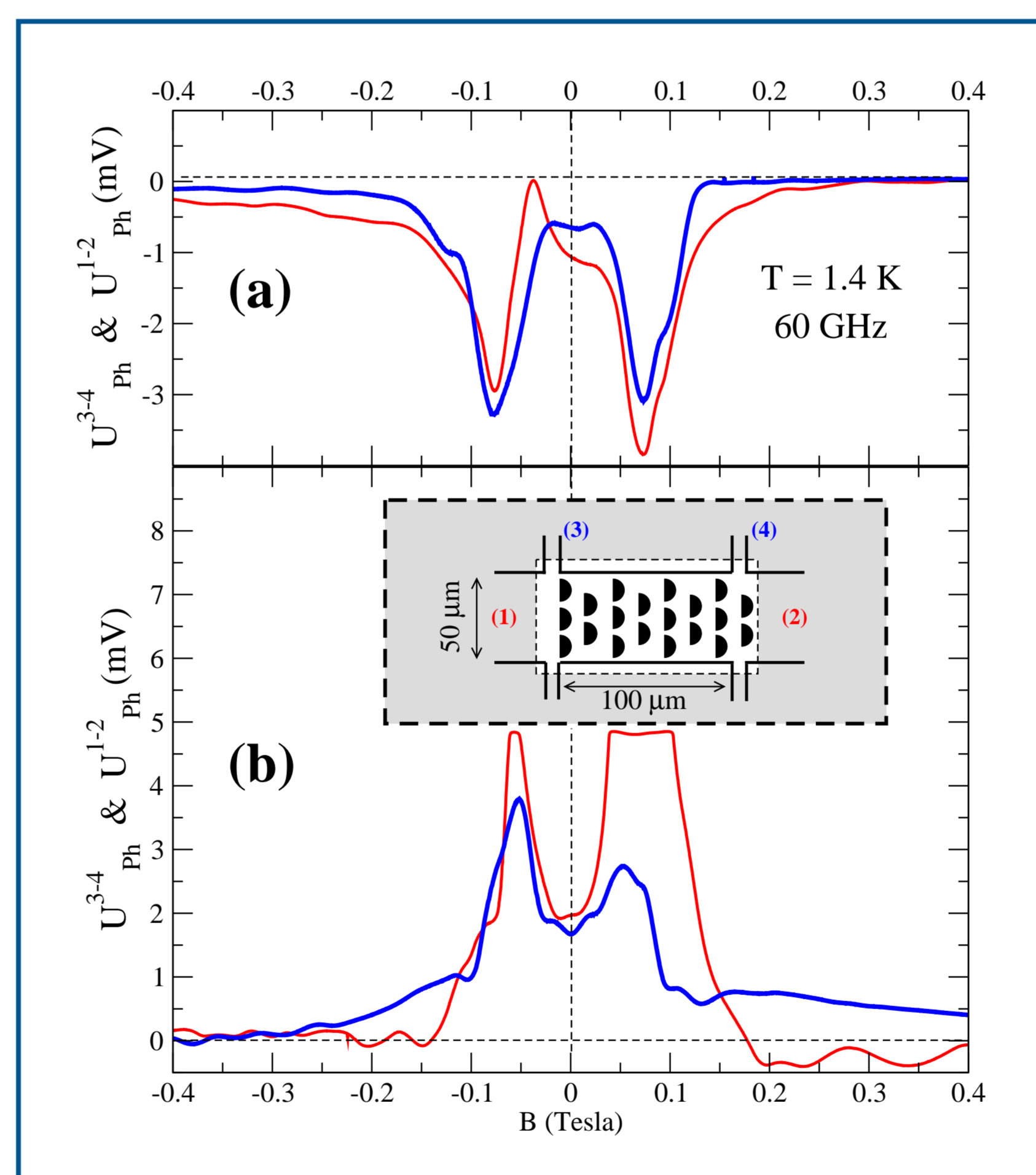
Two samples for this work have been based on MBE-grown AlGaAs/GaAs modulation-doped hetero-junction, having 2DEG at depth of 117 nm below the top of the wafer. Two consecutive Hall bars with lateral sizes  $100 \times 50 \mu\text{m}$  were fabricated in series on the top of each sample, using conventional photolithography technique. A hexagonal lattice of semi-disks, with period  $d = 1 \mu\text{m}$  and semi-disc's radius  $r = 0.25 \mu\text{m}$ , has been fabricated in one of these two Hall bars by means of electron lithography and consequent plasma etching. The second bar was left intact to perform the check of pure 2DES parameters: it demonstrates the value for electron mobility  $\mu = (2 \div 3) * 10^6 \text{ m}^2/\text{Vs}$  at the electron densities  $n_s = (2 \div 3) * 10^{15} \text{ m}^{-2}$  that does correspond to the mean free path of electron in 2DES of about  $10 \div 30 \mu\text{m}$ . Some complementary measurements have been performed on the third sample, which was fabricated in exactly the same way, but with only difference: the antidots of this sample have not semi-disc but circular shape.



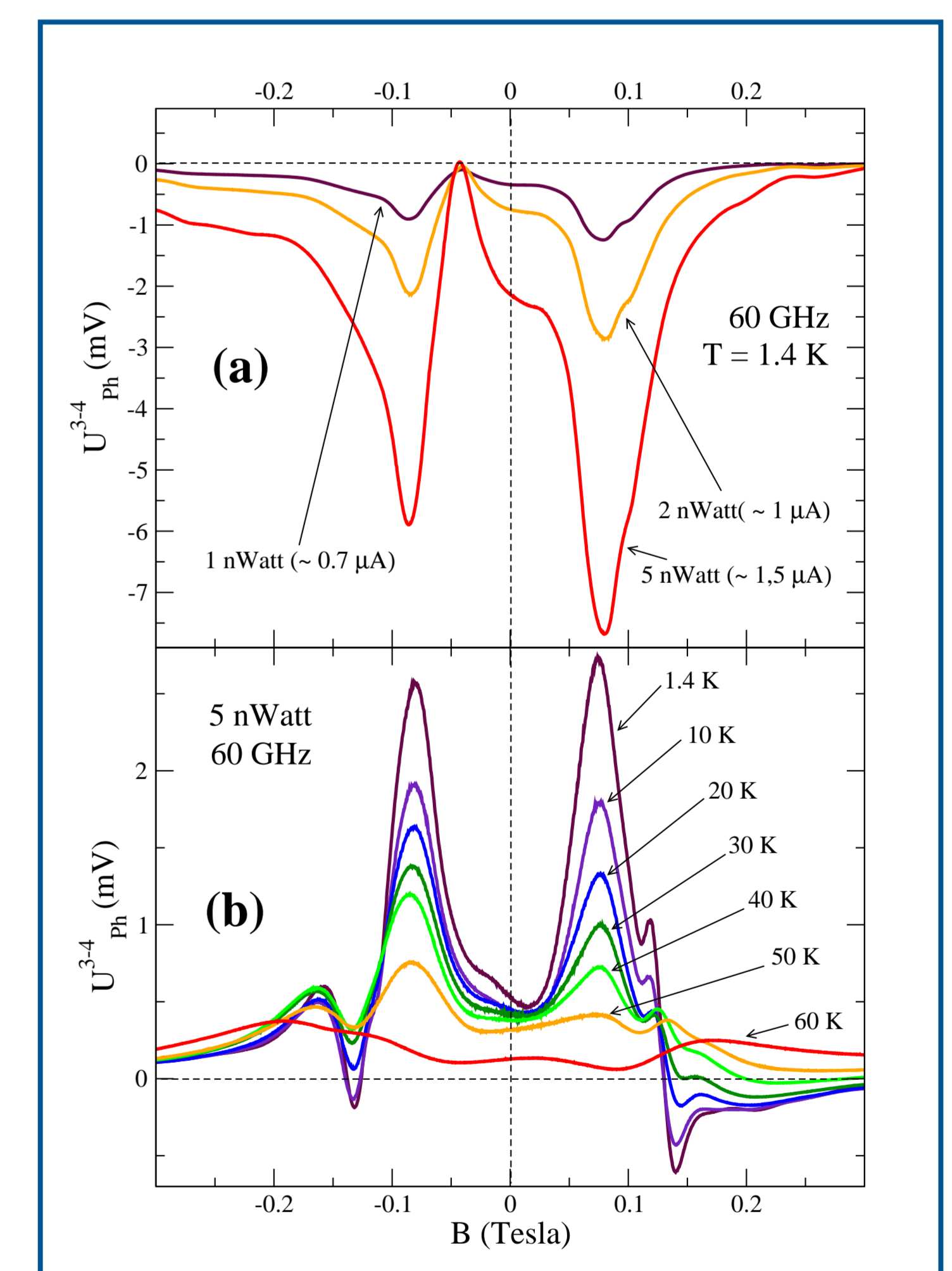
**Figure 1** Magneto-resistivity traces of the antidot lattice (a) and intact part (b) of the sample. The lattice resistivity at zero magnetic field ( $580 \Omega/\text{square}$ ) is about 100 times larger than that of pure 2DES ( $6 \Omega/\text{square}$ ). It means that the antidot scattering playing the major role in the lattice. The commensurability peaks, originating from antidot lattice, are explained in the left inset, while the right inset show the lattice microphotograph.

Follow the figures' captions to understand the measured results...

In conclusion, let us emphasize that the fact of observation of the “ratchet” effect in the lattice with period  $1 \mu\text{m}$  at temperatures close to the liquid nitrogen means that, in principle, it is possible to observe “ratchet” rectification at room temperature. For this aim it just necessary to fabricate such a lattice with smaller period (about  $0.1 \div 0.2 \mu\text{m}$ ), that will be possible in nearest future. It gives the good perspectives to use observed effect in fabrication of principally new kind of electromagnetic radiation detectors, operating in unusually wide frequency range  $1 \div 1000 \text{ GHz}$  and in such way capable to cover both microwave and terahertz ranges.



**Figure 2** Photovoltage study: the rectification signal from the “ratchet” measured under MW irradiation having vector of linear polarisation along (a) and perpendicular to (b) the direction of symmetry breaking. The inset shows the geometry of the system and contacts' alignment of the Hall bar. It is significant that not only zero-field value of the rectification signal, but whole the field-dependent picture changes its sign together with change of irradiation polarization.



**Figure 3** Power (a) and temperature (b) dependence of the rectification signal in the “ratchet” exposed to MW irradiation. 5 nWatt power of MW irradiation excites the “ratchet” current of value  $\sim 1 \mu\text{A}$  (resistance of the lattice is about  $1 \text{ k}\Omega$ ). The temperature dependence has interesting feature: the peaks in weak MF dump with temperature linearly, while the rectification signal at zero MF keeps its value quite stable until 50 K, and then, dumps fast at higher temperatures. The explanation for this rough change of the behaviour is following: at  $T > 30 \div 40 \text{ K}$  the mean free path, connected with background scattering by phonons, becomes comparable with lattice mean free path, so, “ratchet” disappears at 50 K.

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