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# MICROWAVE CONTROL OF TRANSPORT IN NANOSCOPIC STRUCTURES (MICONANO)


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## Abstract

The directed electron transport in a spatially-periodic asymmetrical system – called “ratchet” – is under study. It is a system of two-dimensional electron gas (2DEG) formed in a semiconductor heterojunction and driven by an external linear-polarized microwave (MW) irradiation. The spatial inversion symmetry of the system is broken by introducing of artificial periodic array of asymmetric antidots shaped in semi-disk form. A dc voltage of few mV was observed in the “ratchet” antidot lattice under the MW irradiation. The dc current was studied in two different materials with different antidot lattice parameters in function of magnetic field, temperature, MW polarization and power. The results are in good agreement with recent theory.


## Introduction

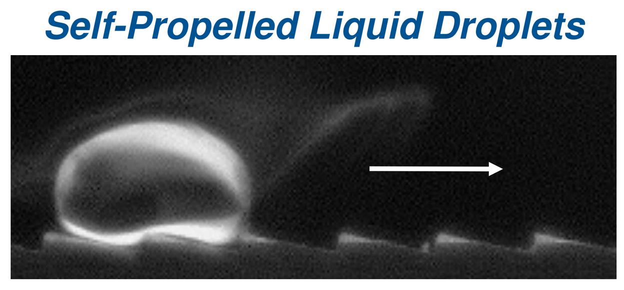
### The Feynman ratchet

In spite of the built asymmetry no preferential direction of motion is possible at equilibrium.

An external energy input could drive the system out of equilibrium and generate a directed motion the direction of which is related to the system configuration.

Examples

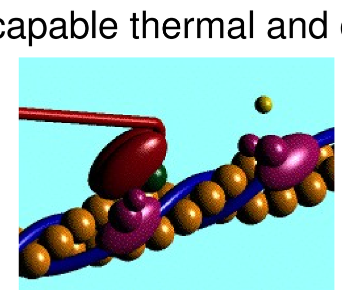
### Self-Propelled Liquid Droplets



Directed motion of a water droplet created by heating of the asymmetric metallic surface.

### Molecular Motors

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

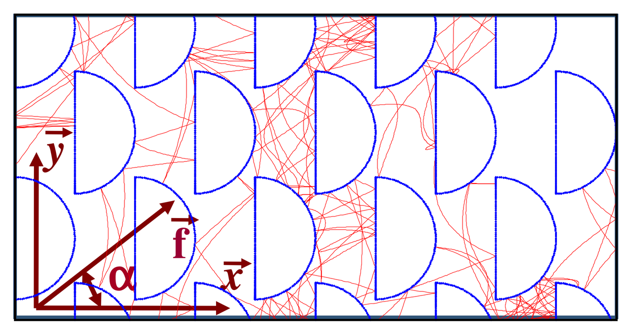


Protein motor (Actin Myosin) use chemical energy (ATP) to make directed motion along a polymer filament (which is periodic and asymmetric).

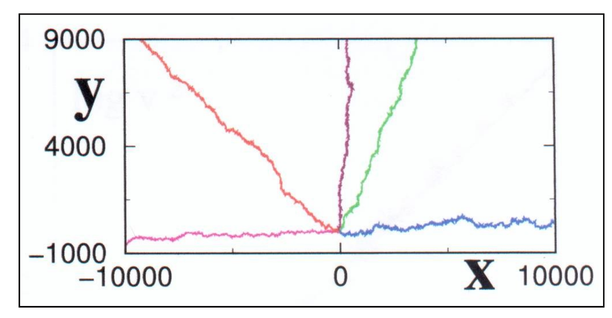

Refs: R.D. Astumian & P. Hanggi, Phys. Today 55, 33 (2002); F. Julicher et al., Rev. Mod. Phys. 69, 1269 (1997); H. Linke et al., Phys. Rev. Lett. 96, 154502 (2006); P. Reimann, Phys. Rep. 361, 57 (2002).


## The Theory

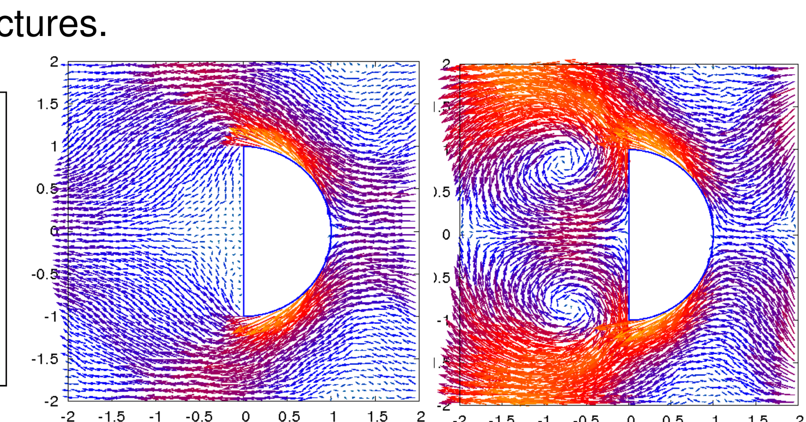
Exposed to the linear-polarised microwave irradiation, asymmetric antidot lattice (mesoscopic periodical system of scattering centres realized on semiconductor heterojunction with 2DEG) will play a role of quantum ratchet, while the MW itself will serve as driving force and as external energy input (whicht will drive the system out of equilibrium) at the same time. ⟶ Directed electron motion induced by MW in such structures.



Modified “Galton board” – triangular lattice of rigid semidisks. Small scale: chaotic trajectory.




Large scale: linear trajectory. Directed transport for one trajectory at various polarizations of radiation: $\alpha = 0, \pi/8, 0.21\pi, \pi/4, \pi/2$ (from left to right clockwise).



Left : Ratchet flow without electron-electron interactions
Right : Ratchet flow with strong interactions
Polarisation angle is $\alpha = 0$

Theoretical prediction on ratchet velocity

$$\frac{v_f}{V_F} = \frac{\tau(eE\tau V_F)^2}{12E_F^2\tau_c(1+\omega^2\tau^2)}$$

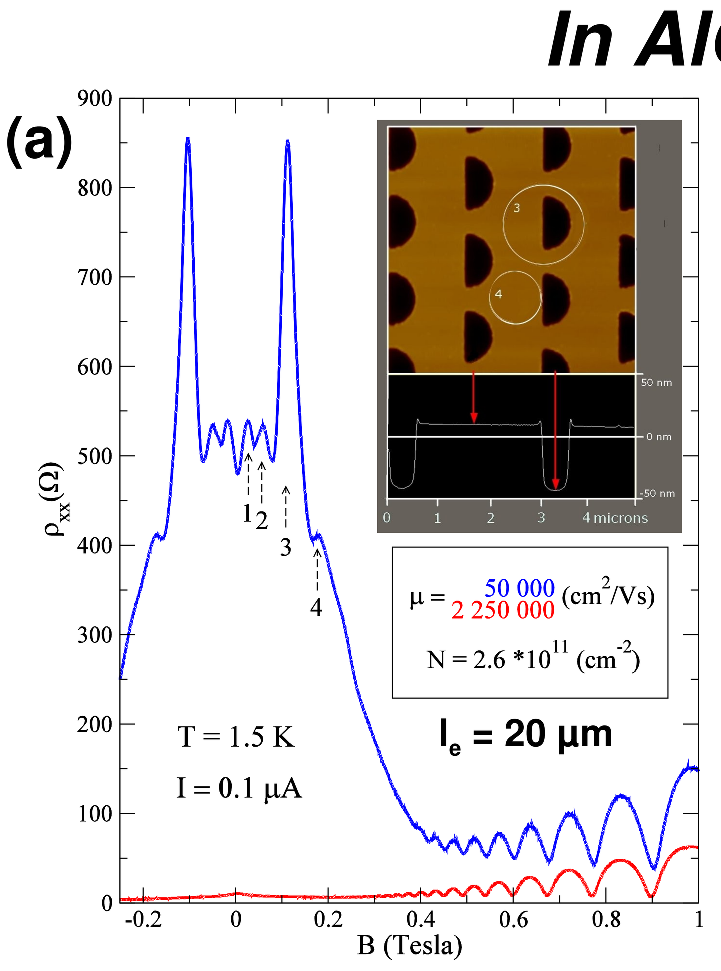
By changing the linear polarization of the microwave radiation in presented ratchet it is possible to change the direction of the transport. The polarization dependence is strongly dependent on electron-electron interaction strength.


A.D. Chepelianskii & D.L. Shepelyansky, Phys. Rev. B 71, 052508, (2005); G. Cristadoro & D.L. Shepelyansky, Phys. Rev. E 71, 036111 (2005); A.D. Chepelianskii, EPJB 52, 389 (2006); A.D.Chepelianskii, M.V.Entin, L.I.Magarill, D.L.Shepelyansky EPJB 56, 323 (2007); arXiv:0808.2970 [cond-mat]

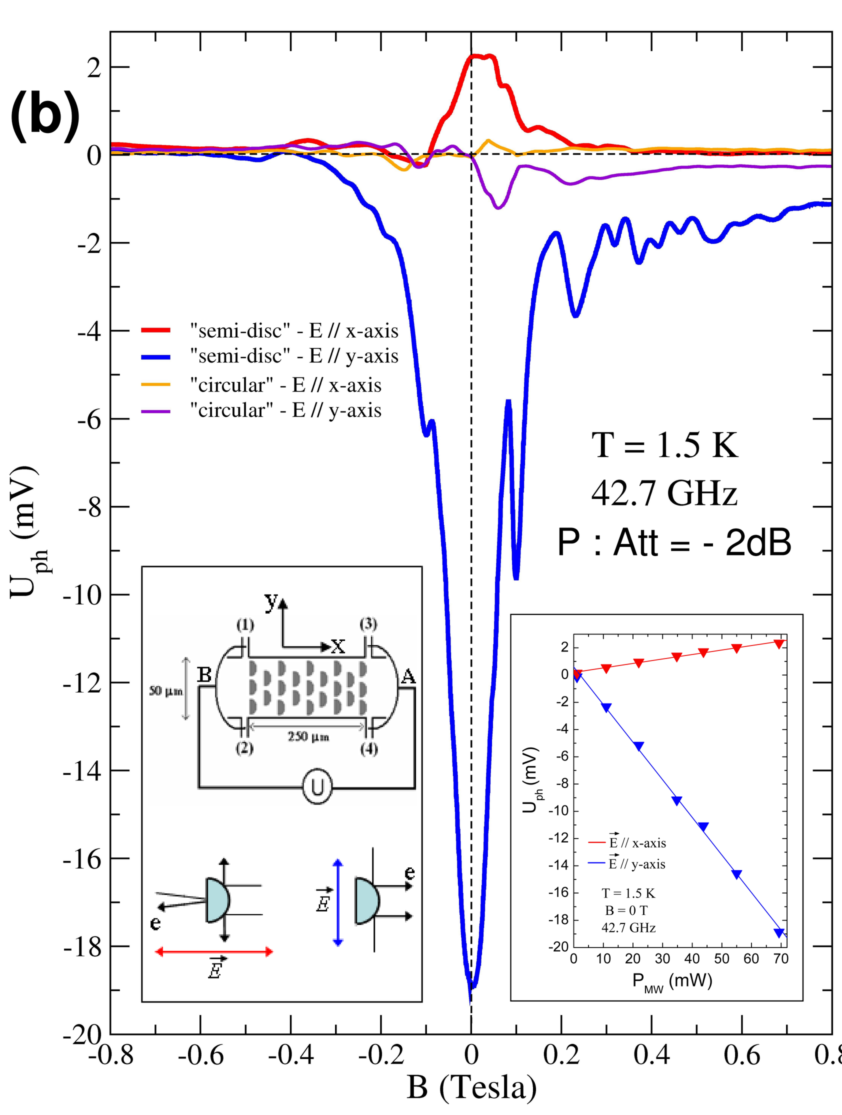

## The Experiment

### In AlGaAs/GaAs

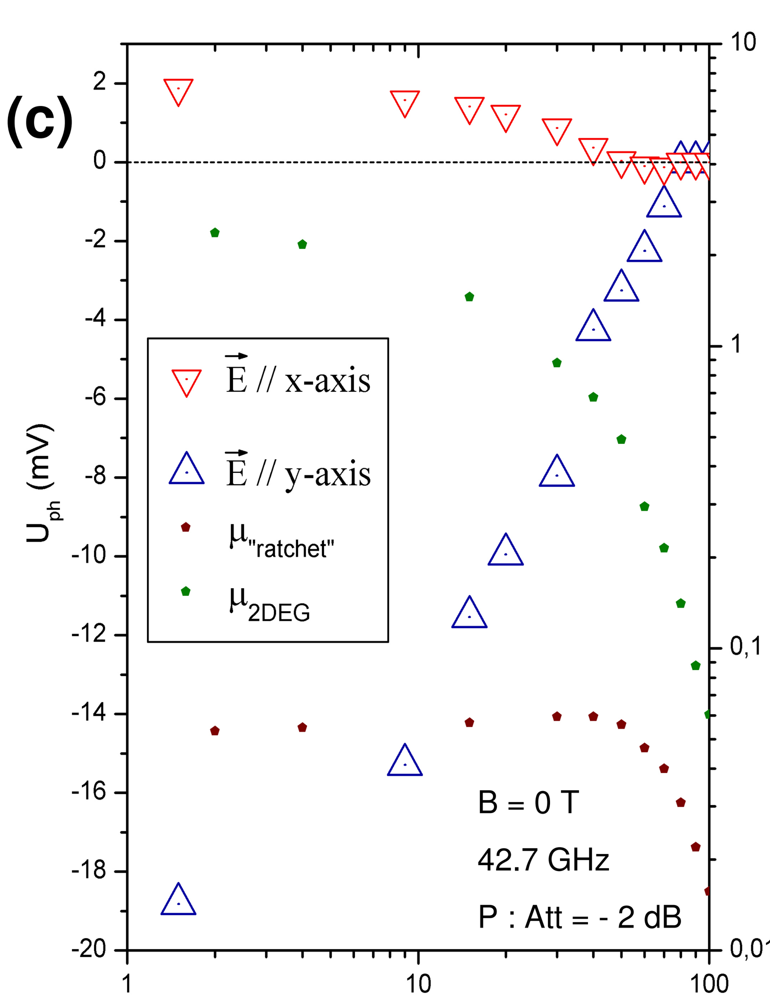
(a)




(b)




(c)




-Fig (c) shows the temperature dependence of the ratchet signal and that of the mobility in ratchet part and intact 2DEG part. At about 70 K the electron mean free path is equal to 1.7 µm and becomes comparable to the lattice period. That explains why the ratchet signal disappears at this temperature.

Samples are high mobility 2DEG based on AlGaAs/GaAs heterostructures with Hall bar geometry. The lattices of semicircular antidots fabricated by EBL and plasma etching have the dimensions 250 × 50 µm² and the parameters : period = 1.5 µm and antidot radius = 0.5 µm. Lattices with the same parameters but with circular antidots were also fabricated.

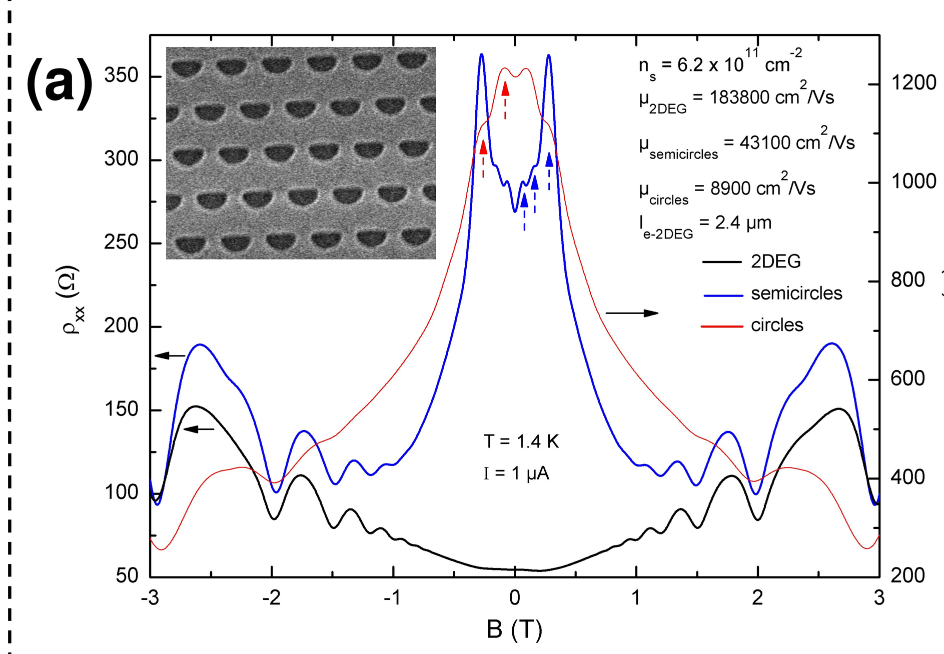
-Fig. (a) shows the magnetotransport measurements in a sample (red correspond to pure 2DEG and blue to the antidot lattice) and an AFM image of a lattice with etching profile.

-Fig. (b) presents the photovoltage measurements: magnetic field dependence of the dc-voltage induced by the linear polarized microwaves in the ratchet antidot lattice and in a lattice of circular antidots, for two directions of polarization. The effect depends on MW polarization, it goes to zero in weak magnetic fields. No ratchet effect in symmetric lattices. The insets show the measurement configuration and the scattering process (to the left) and the power dependence of the dc-voltage (to the right).

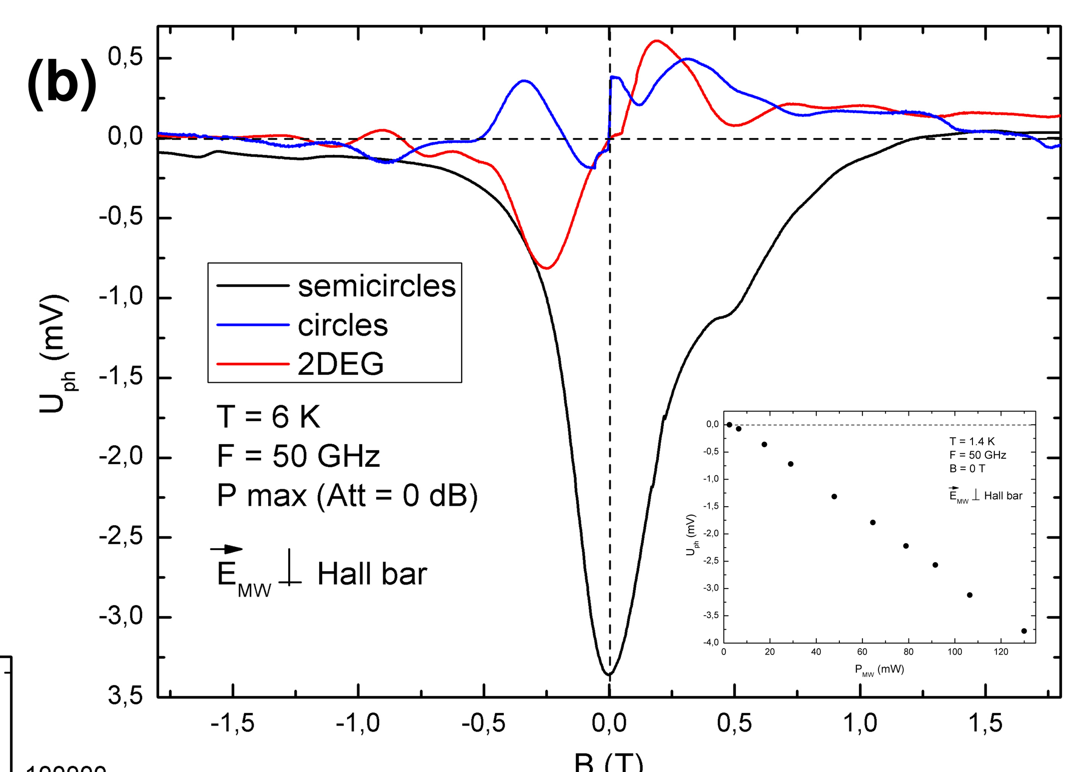

S. Sassine et al., Phys. Rev. B 78, 045431 (2008). [Selected for the August 11, 2008 issue (Volume 18, Issue 6) of the Virtual Journal of Nanoscale Science & Technology].


### In Si/SiGe

(a)




(b)

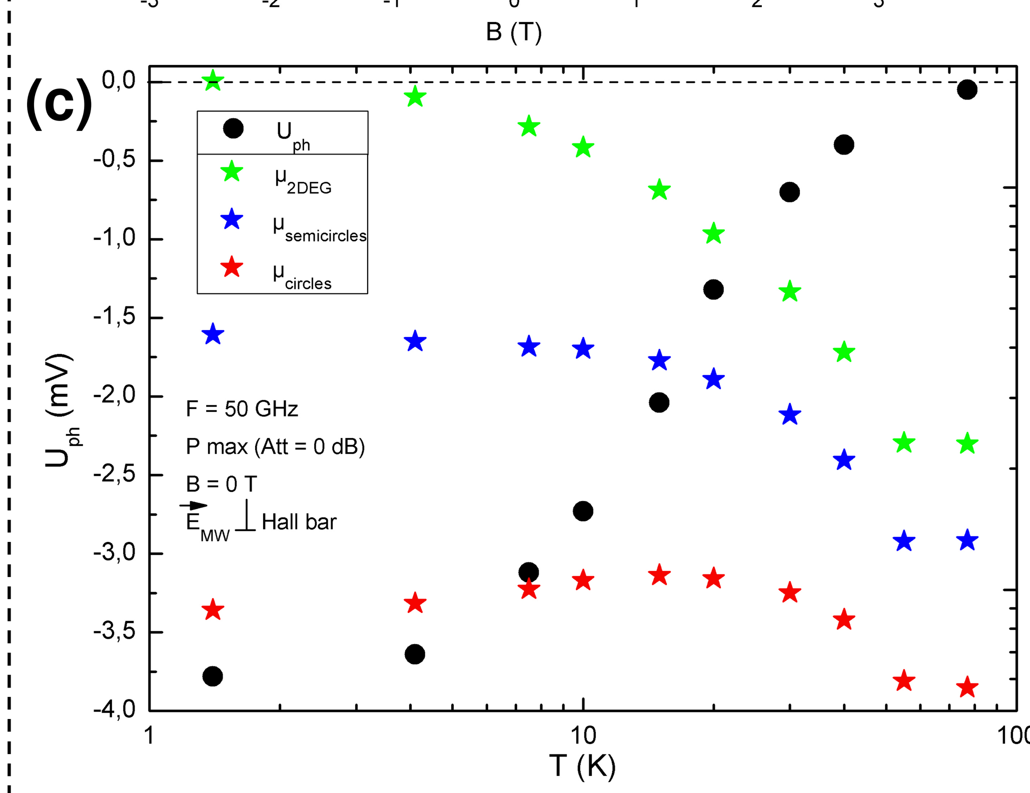



Samples are high mobility 2DEG based on Si/SiGe heterostructures with Hall bar geometry. The lattices of semicircular antidots have the dimensions 80 × 50 µm² and the parameters : period = 0.6 µm and antidot radius = 0.2 µm. Lattices with the same parameters but with circular antidots were also fabricated.

-Fig. (a) shows the magnetotransport measurements in one sample and a SEM image of a lattice.

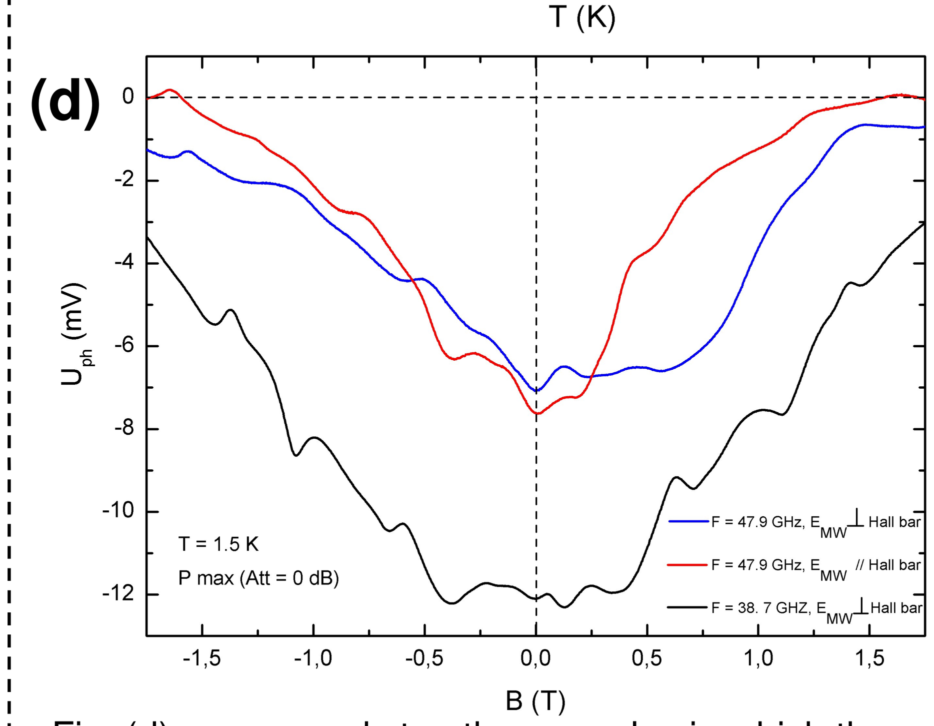
-Fig. (b) presents the photovoltage measurements: magnetic field dependence of the dc-voltage induced by the linear polarized microwaves in the ratchet antidot lattice, in a lattice of circular antidots and in a pure 2DEG part. The effect goes to zero in weak magnetic fields. No ratchet effect in symmetric lattices and in pure 2DEG. The right inset show the power dependence of the dc-voltage. It is a linear dependence.

(c)




-Fig. (c) shows the temperature dependence of the ratchet signal and that of the mobility in ratchet part, intact 2DEG part and circles antidots part. The effect disappears at liquid nitrogen temperature (77 K) since the electron mean free path becomes equal to 0.3 µm at 77 K, this is comparable to the antidots spacing (0.2-0.4 µm).

(d)




-Fig. (d) corresponds to other samples in which the mobility is 2 times smaller than in previous samples (of Si/SiGe). A square antidot array of 500 × 500 µm² (lattice parameters: period = 0.6 µm and radius = 0.2 µm) is fabricated between two metallic electrodes used to measure the signal.

- A MW absorber diaphragm with rectangular hole (1 × 2 mm²) was used to cover the sample contacts and the sample holder.

- The modulation technique have been used also and it gives similar results…

In **conclusion**, the observation of the “ratchet” effect in antidot lattices realized on two materials (AlGaAs/GaAs and Si/SiGe) at liquid nitrogen temperatures means that it is possible to observe “ratchet” rectification at higher temperatures. For this aim it is necessary to fabricate such lattices with smaller period. It gives perspectives to fabricate **new electromagnetic radiation detectors** sensitive to polarization, having linear response to the radiation power, and operating in MW and terahertz frequency ranges. Also, perspectives to fabricate **micro-scale-sized current generators** is proposed since our “ratchet” lattice acts as a current generator.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