Evanescent wave properties

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Polarization state of the evanescent wave

Introduction

Polarization properties of electromagnetic waves become particularly important, when we consider propagation in media with boundary conditions. Examples include optical fibers and planar waveguides or simply the interface between media with different refractive indices.
Note taht the polarization behavior and features of the EW are rarely considered in details in the optics literature

Theory

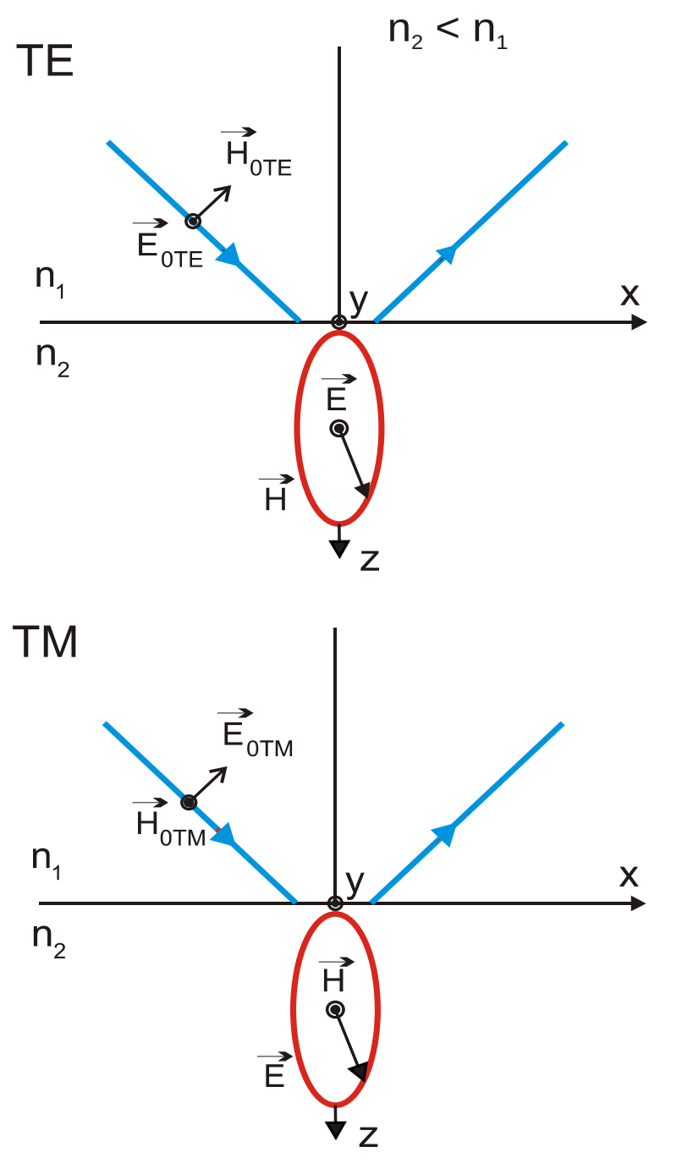
Let us assume a monochromatic plane wave that reaches the border of two nonmagnetic media with an angle larger than the critical angle. For any case of polarization of the incident wave, it is sufficient to perform calculations and measurements for TE and TM polarizations only.
It is useful to calculate the EW electric field components in order to extract the information about phase relations between the components of the electric field vector. From Fresnel equations for angles greater than the critical angle:

$$\frac{E_x}{E_{0TM}} = \frac{2\cos\theta\sqrt{\sin^2\theta - n_{21}^2}}{\sqrt{n_{21}^4\cos^2\theta + \sin^2\theta - n_{21}^2}}\, e^{\left(-i\left(\delta^{TM}+\pi\right)/2\right)}$$

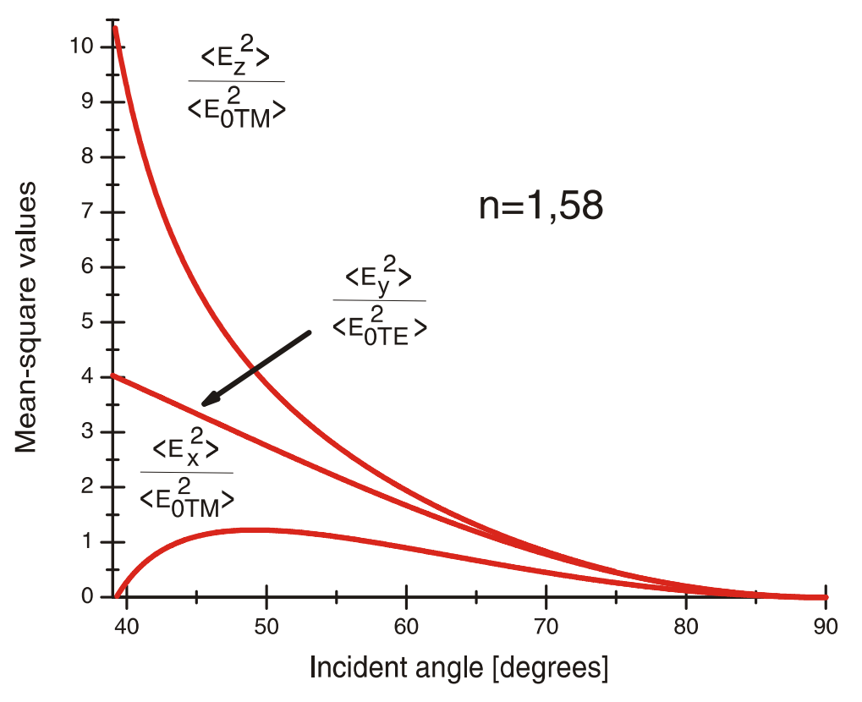
$$\frac{E_z}{E_{0TM}} = \frac{2\cos\theta\sin\theta}{\sqrt{n_{21}^4\cos^2\theta + \sin^2\theta - n_{21}^2}}\, e^{\left(-i\delta^{TM}/2\right)}$$

$$\frac{E_y}{E_{0TE}} = \frac{2\cos\theta}{\sqrt{1-n_{21}^2}}\, e^{\left(-i\delta^{TE}/2\right)}$$

where $n_{21}=n_2/n_1$ and δ^{TM} and δ^{TE} denote the phase shifts acquired by the TM and TE components of the electric vector after total internal reflection.



Mean-square electric field components at the interface for n_1=1.58 and n_2=1 as a function of the angle of incidence.



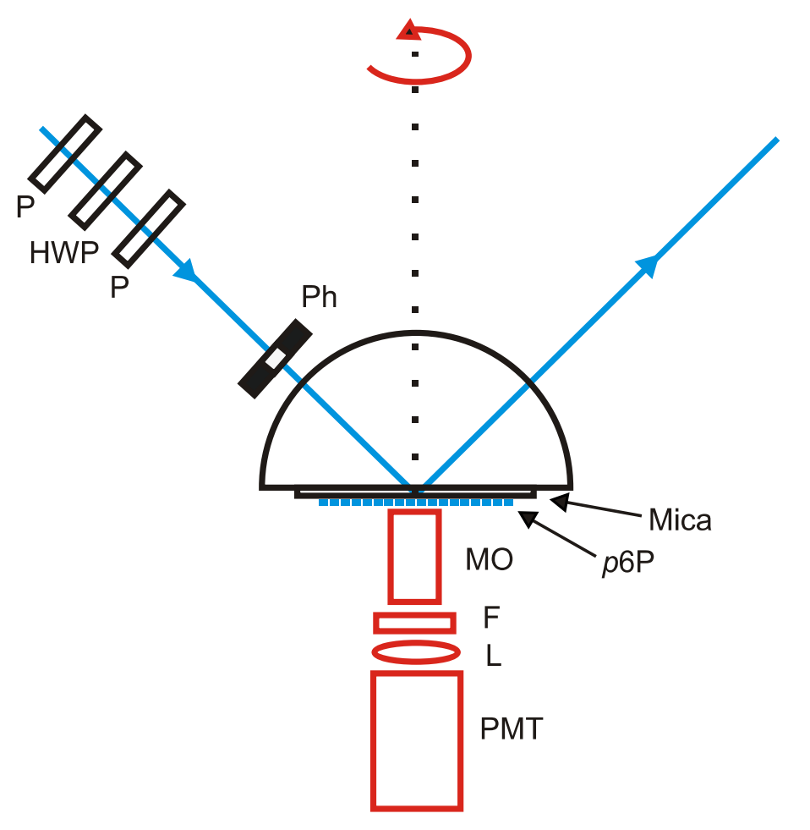
Experiment 1

Abstract

We present results from a direct measurement of the elliptical character of the evanescent part of linearly polarized light, undergoing total internal reflection in a quartz half-sphere. These results have been obtained by invoking polarization-sensitive and light-emitting organic nanofibers. The angular dependencies of the mean-square electric field vector components parallel and perpendicular to the surface plane agree with predictions from the Fresnel equations.

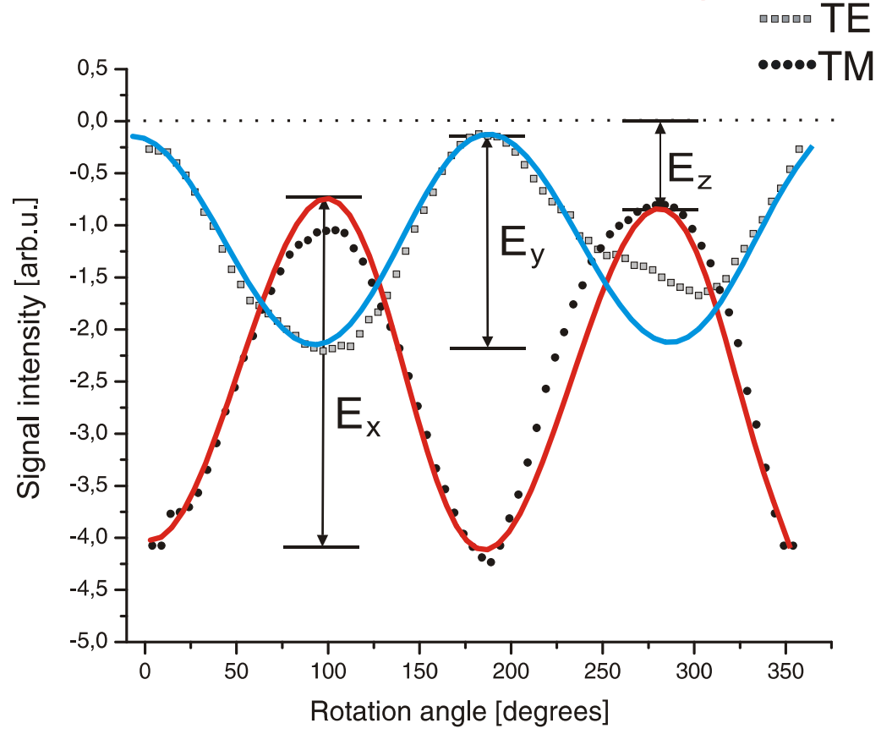
Experimental Setup

The main idea of the experiment is to rotate a flat domain of parallel-oriented needles (*p*-6p) over an angle of 2π and to excite the domain with polarized UV (325 nm) EW radiation while detecting simultaneously the emitted fluorescence (max. 430 nm) intensity. Two specific properties of the nanofiber samples are used. Firstly, owing to their special growth mechanism, all the nanofibers are oriented strictly parallel to each other. Secondly, the height distribution function of the nanofibers for given growth conditions is very narrow, i.e., they all have roughly the same height.



MO - microscope objective; F - filter; L - lens; PMT - photomultiplier; Ph - pinhole; P. - polarizer; HWP - half-wave plate

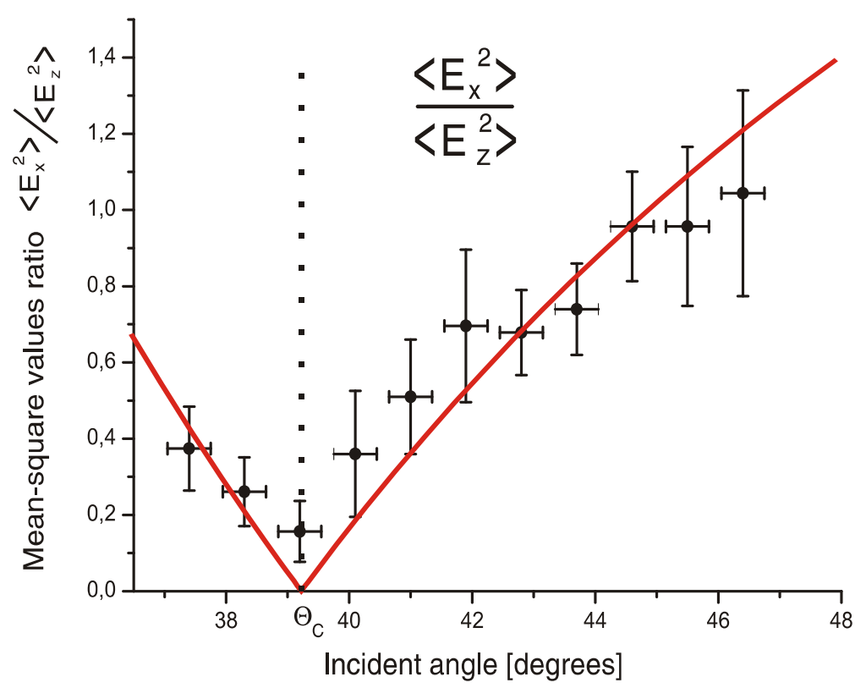
Typical detection signal

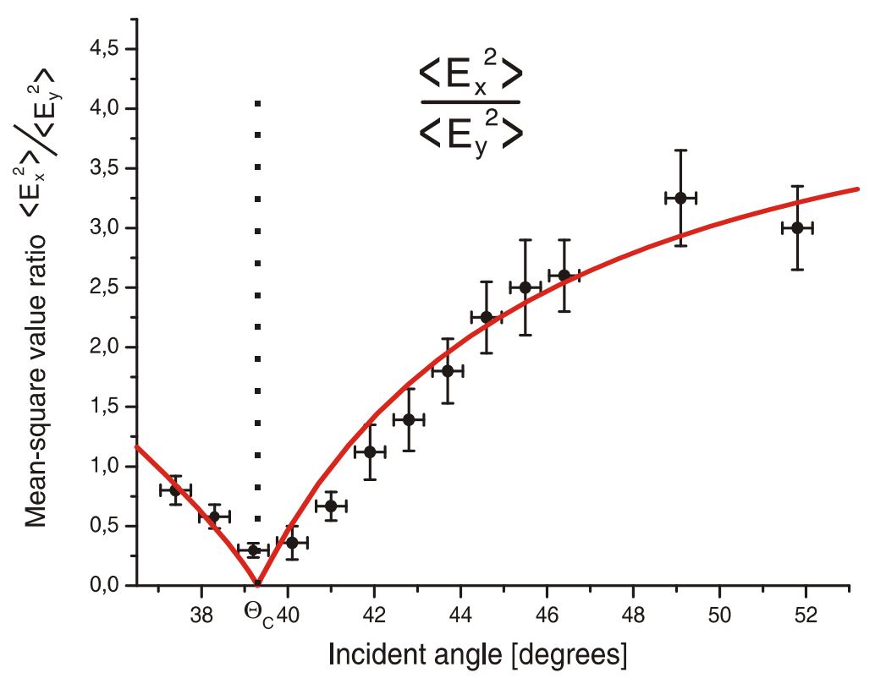


During sample rotation we observed fluorescence maxima corresponding to a superposition of the EW's electric vector with the molecular transition dipole moments. We performed a series of measurements for both the TE and the TM cases with the same beam intensity 500 mW/cm² for different incident angles in the range below and above the critical angle.

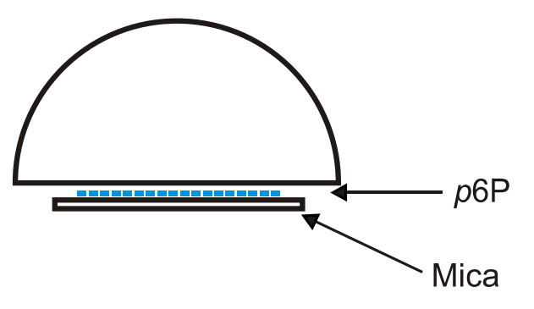
Results

Experimental and theoretical results for "two-phase" TIR configuration (mica — air).
We emphasize very good quantitative agreement of experimental and theoretical curves after multiplying theoretical curves by a facror of 5.

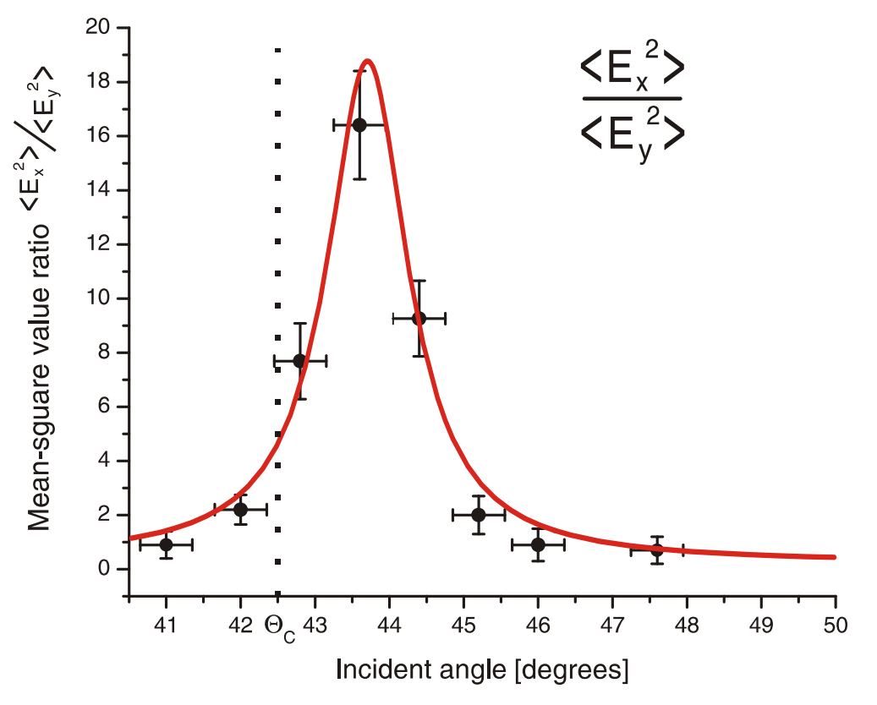




Results for "three-phase" configuration (quartz — air — mica):



0.2 μm air gap between the mica and the quartz halfsphere

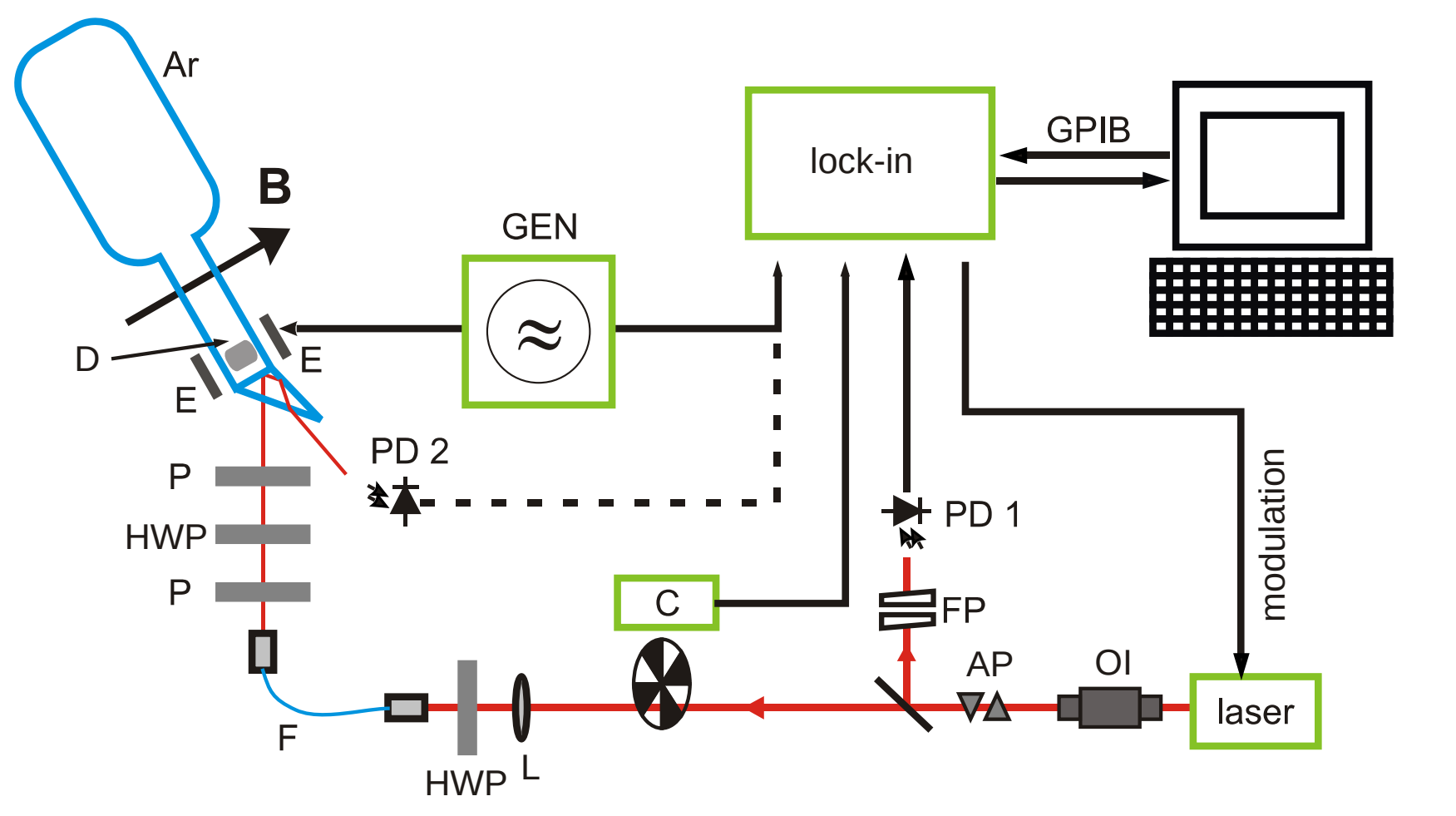


Experiment 2

Abstract

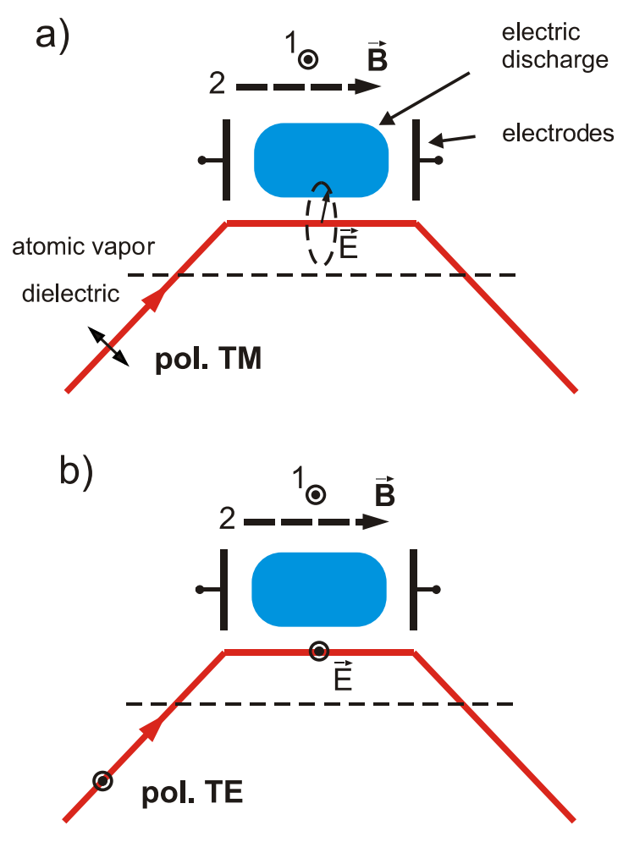
We have used optogalvanic spectroscopy to observe Zeeman effect in the evanescent wave in Ar gas using single-mode diode laser. The idea was to use homogenous external magnetic field to observe dfferent π and σ Zeeman split lines contribution. We have studied two orthogonal directions of external magnetic field and electric vector of the linearly polarized incident wave with respect to the plane of incidence. The analysis of relative line strengths leads to the determination of the polarization state of the evanescent wave.

Experimental setup



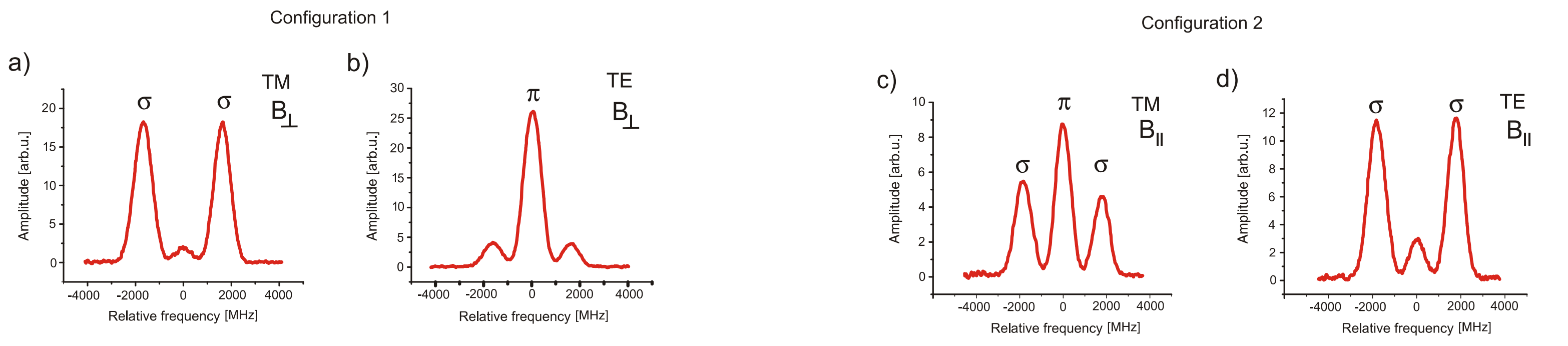
OI-optical isolator, AP-anamorphic prisms, FP- Fabry -Pérot interferometer (FSR = 724 MHz), PD- photodiode, C - optical chopper, L - lens, F -optical fiber, P - polarizer, HWP - half wave plate, Ar - glass cell with Argon, E - electrodes, D - electric discharge in gas, GEN -RF generator

The two different configurations of external magnetic field, perpendicular "1" and parallel "2" to the plane of incidence:

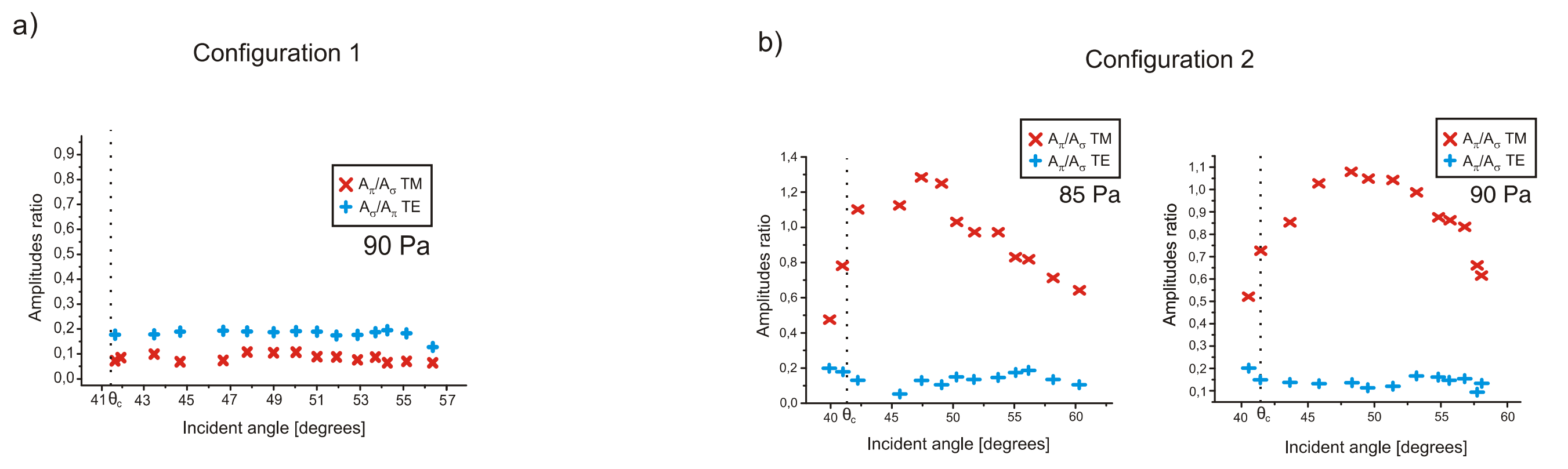


Experimental results

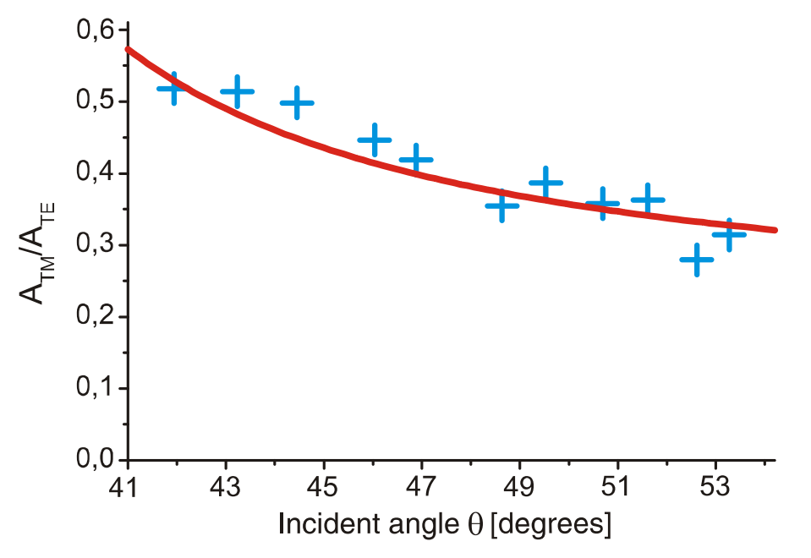
Exemplary signals with applied external magnetic field for appropriate configurations are shown below. In configuration "1", where magnetic field is perpendicular to the plane of incidence, only E_y may be associated with the π component of the Zeeman spectrum. Both E_z and E_x, may be associated with the σ component. In the configuration "2", where the magnetic field is parallel to the plane of incidence, only E_x may be associated with the π component. Both, E_y and E_z, may be associated with the σ component.



We define the ratio of π and σ lines intensities and show their dependence on the angle of incidence. These ratios for TM polarization case in the configuration 2 present literally the elliptical character of EW.



For further analysis, we compare experimental amplitudes of σ components (configuration "2") for TM andTE polarization of the incident beam with theoretical transmission intensity coefficients. The scaling factor between the theoretical curve and experimental results is about 1/4.

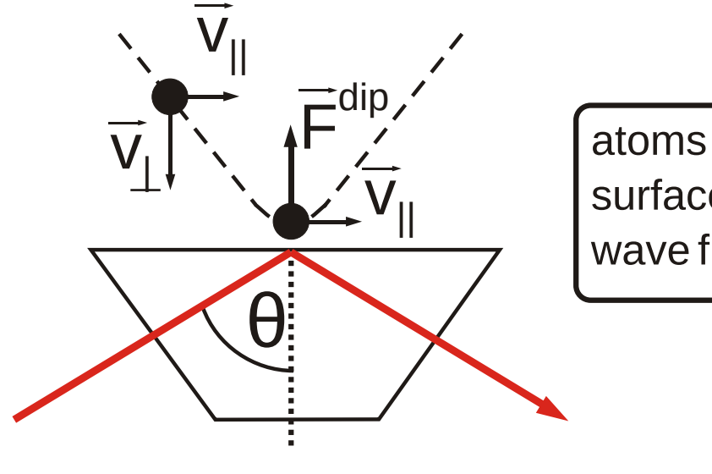


This is probably associated with the anisotropy of the gas medium in close vicinity (150 nm) of the prism surface. The proximity of the surface causes the optical properties of atoms depend on the direction of polarization of the evanescent wave. The magnitude of that modification depends on the direction of the induced atomic dipole according to the border plane.

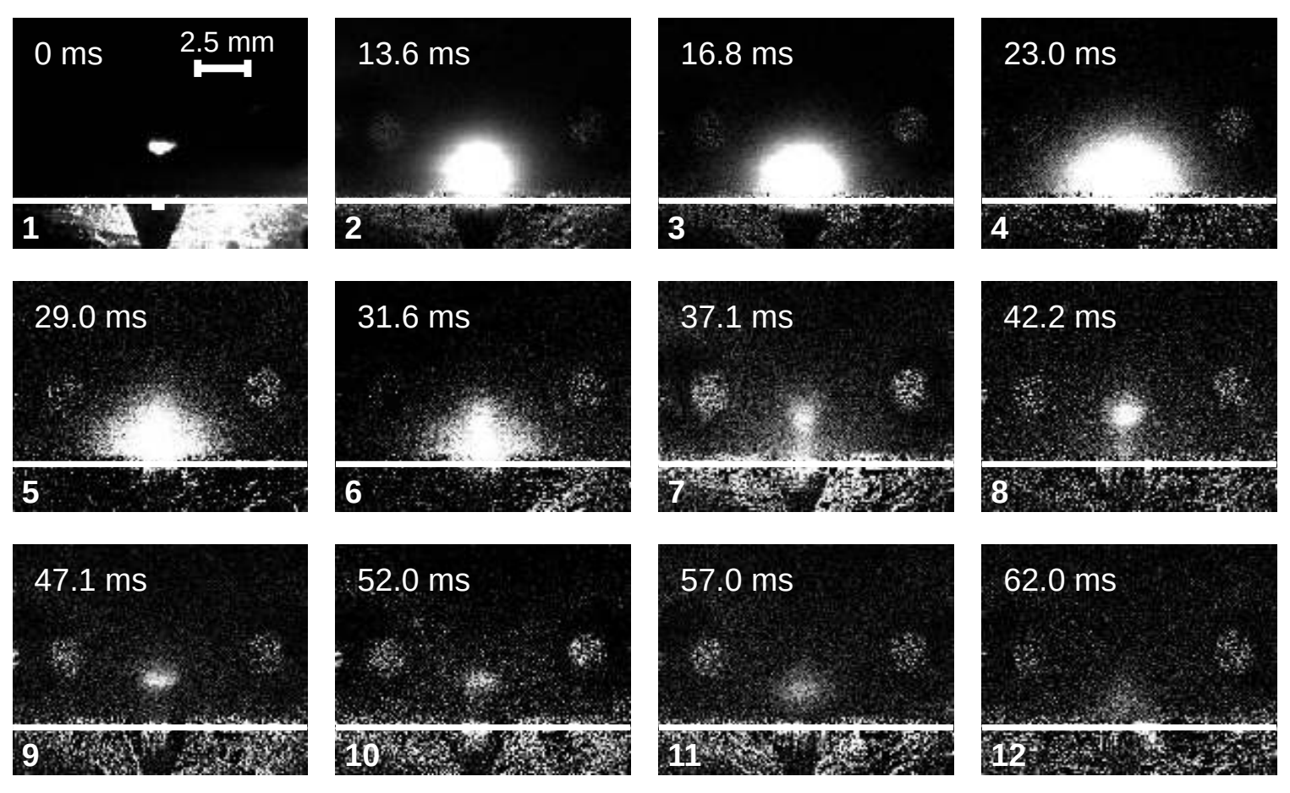
Optical dipole mirror for cold Rubidium atoms

One of the methods of collecting a great number (of at least a few thousands) of neutral atoms in the gas phase in the vicinity of the solid state surface is to use the dipole magnetic and optical traps. The main component of the latter ones are elastic and inelastic optical dipole mirrors. Here we present the experimental realization of the dipol mirror for cold Rubidium atoms. The dipole force acting on atoms moving in the area of a blue-detuned evanescent wave was used. The constructed dipole mirror have several advantages: great repeatability of its parameters, easy regulation of the initial height of the atomic cloud above the dielectric surface, it has efficient detection system of the reflected atoms, it allows theare observation of both elastic and inelastic reflected atoms, it is relatively simple and cheap. The described setup is also the first and most important step towards achieving the gravito-optical surface trap (GOST). This trap allows one not only to reflect atoms but also to trap them and cool at a distance of about 1 μm from the dielectric surface.

principle of the optical dipole mirror:



atoms are reflected close to the dielectric surface in the blue detuned evanescent wave field thanks to repulsive dipole force



Outlook

The mirror will be used for:
- the measurements of the de Broglie phase behaviour of the atoms reflected from a vibrating dipole mirror
- the investigation of the evanescent wave polarization state. We are going to use two methods:
  - to measure the light pressure acting on the reflected atoms when they in the field of a resonant evanescent wave
  - to investigate the optical pumping of cold atoms in the presence of the resonant evanescent wave
- the investigation of the influence of the dielectric surface on the atom radiative properties

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