Optical dipole mirror for cold Rubidium atoms

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ABSTRACT

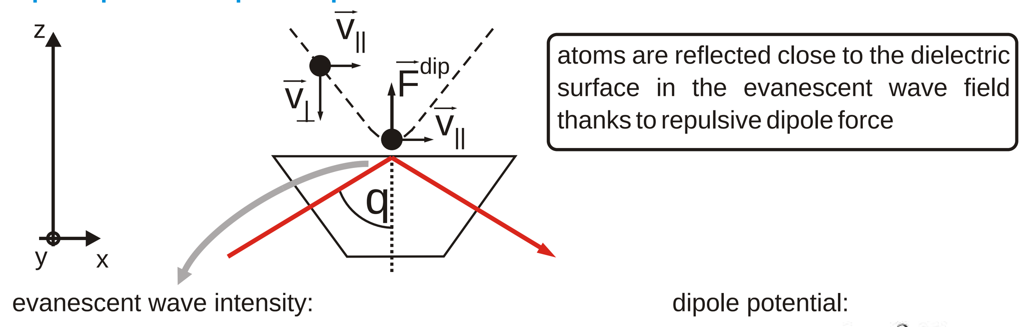
One of the methods of collecting a great number (of at least a few thousands) of neutral atoms in the gas phase in the vicinity of the solid state surface is to use the dipole magnetic [1] and optical [2] traps. The main component of the latter ones are elastic and inelastic optical dipole mirrors. In this work we present the experimental realization of the dipol mirror for cold Rubidium atoms. The dipole force acting on atoms moving in the area of 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 reflected atoms, it allows the observation of both elastically and inelastically 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 the distance of about 1 mm from the dielectric surface.

HISTORY

- 1982 – R.J. Cook and R.K. Hill proposed for the first time the elastic dipole mirror for neutral atoms based on blue detuned evanescent wave
- 1988 – first experimental realization of optical dipole mirror for thermal atomic beam [3]
- 1990 – first realization for atoms falling from a magneto-optical trap [4]
- 1995 – inelastic optical dipole mirrors are proposed [5]
- 1995 – first demonstration of inelastic reflection for thermal atomic beam [6]
- 1997 – gravito-optical surface trap (GOST) was constructed. Temperature as low as 3 mK was achieved thanks to subsequent inelastic reflections [7]
- 2004 – two dimensional BEC was achieved thanks to applying evaporative cooling in so called microtrap based on GOST [8]

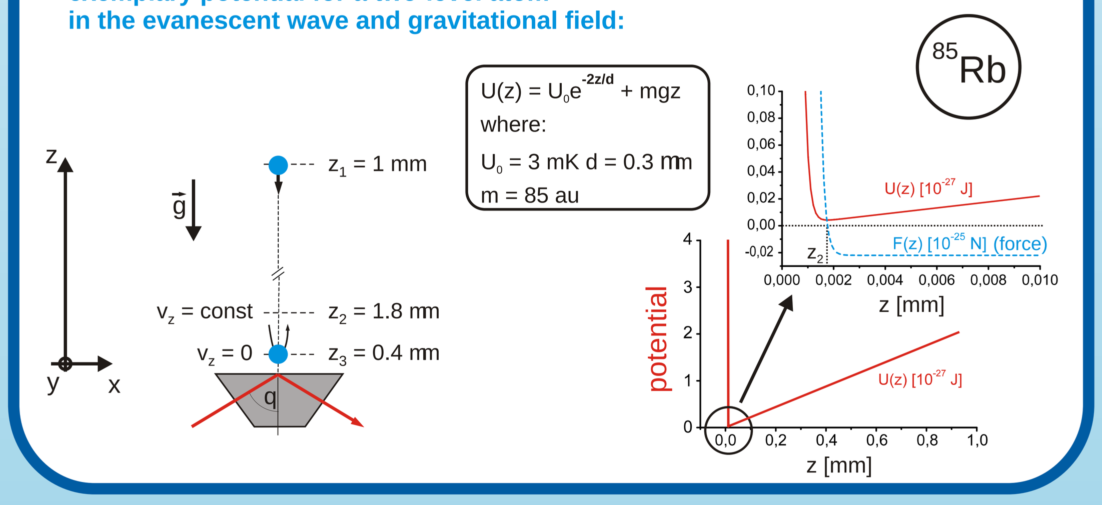
GENERAL INTRODUCTION

principle of the optical dipole mirror:



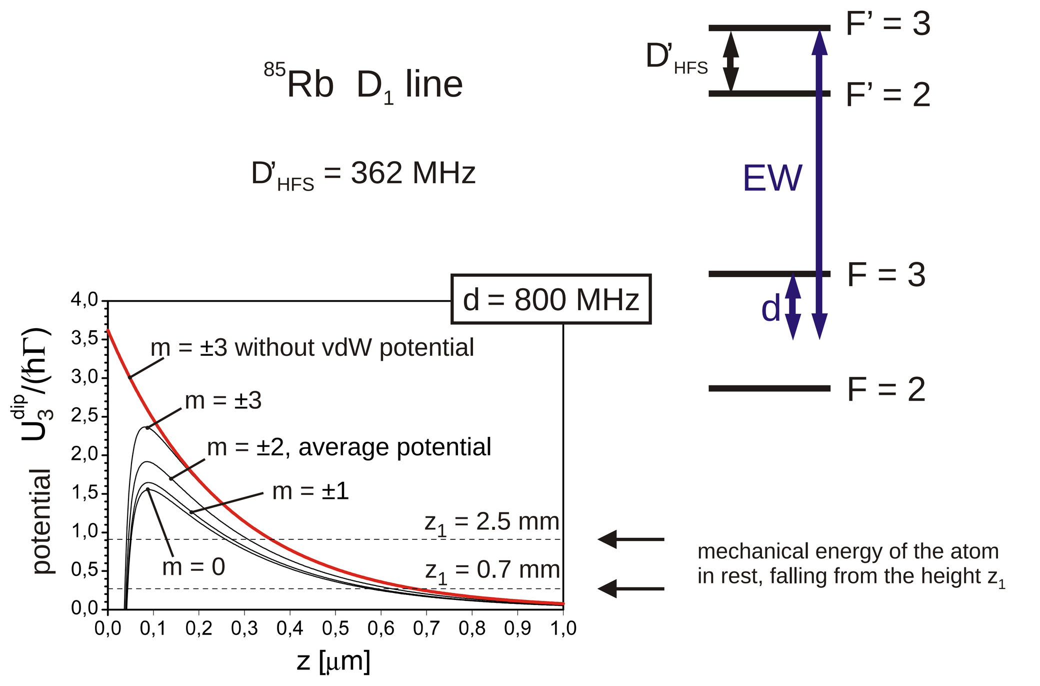
$$I(\vec{r}) = I_0 \exp\left(-\frac{x^2}{w^2\cos^2\theta}\right)\exp\left(-\frac{y^2}{w^2}\right)\exp\left(-\frac{2z}{d}\right) \longrightarrow U^{dip}(\vec{r}) = \frac{3\pi c^2}{2\omega_0^3}\frac{\Gamma}{\delta} I(\vec{r})$$

exemplary potential for a two-level atom in the evanescent wave and gravitational field:



POTENTIALS

multilevel structure and van der Waals potential included:



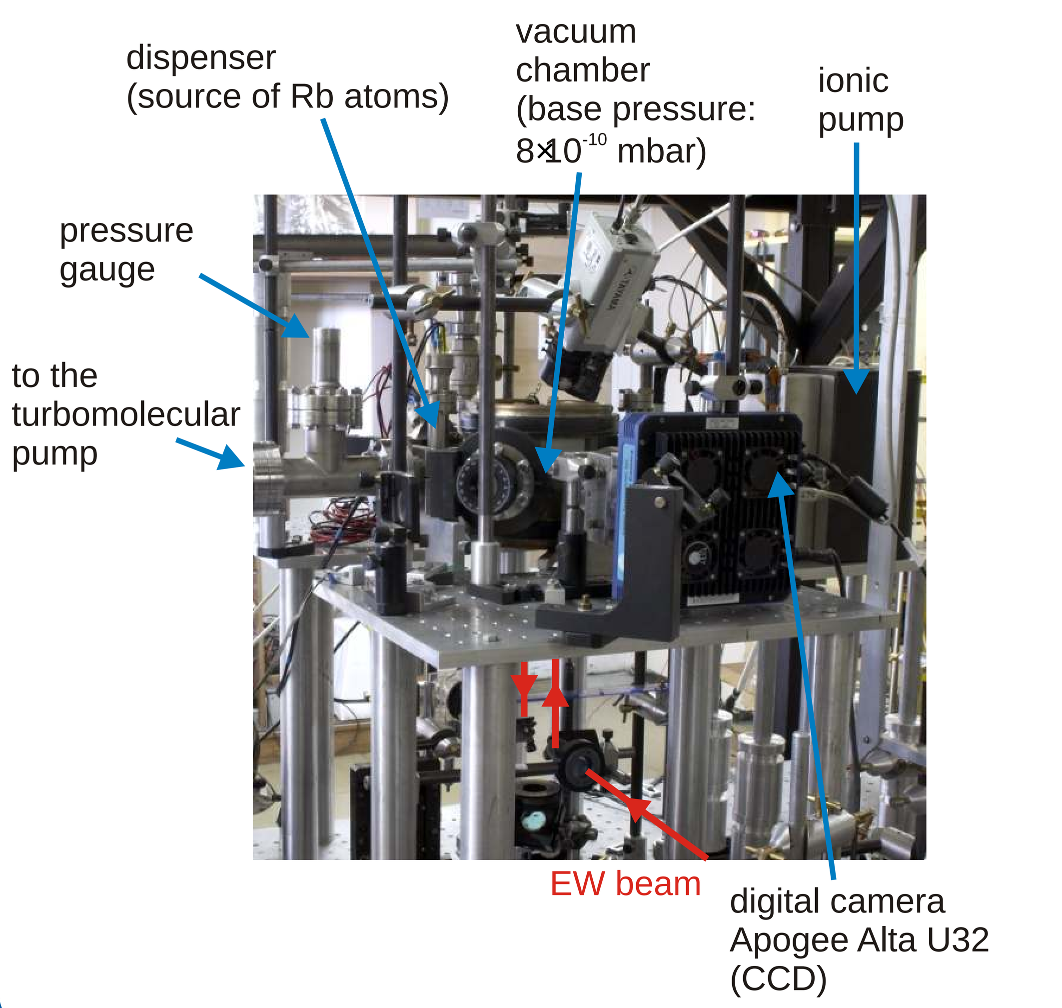
$$U_{3m}^{dip} = \frac{3}{16}\frac{\Gamma\lambda^3}{\pi^2 c} I(z) \frac{1}{2\pi}\left(\frac{|C_{3m,2m}|^2}{\delta + \Delta'_{HFS}} + \frac{|C_{3m,3m}|^2}{\delta}\right)$$

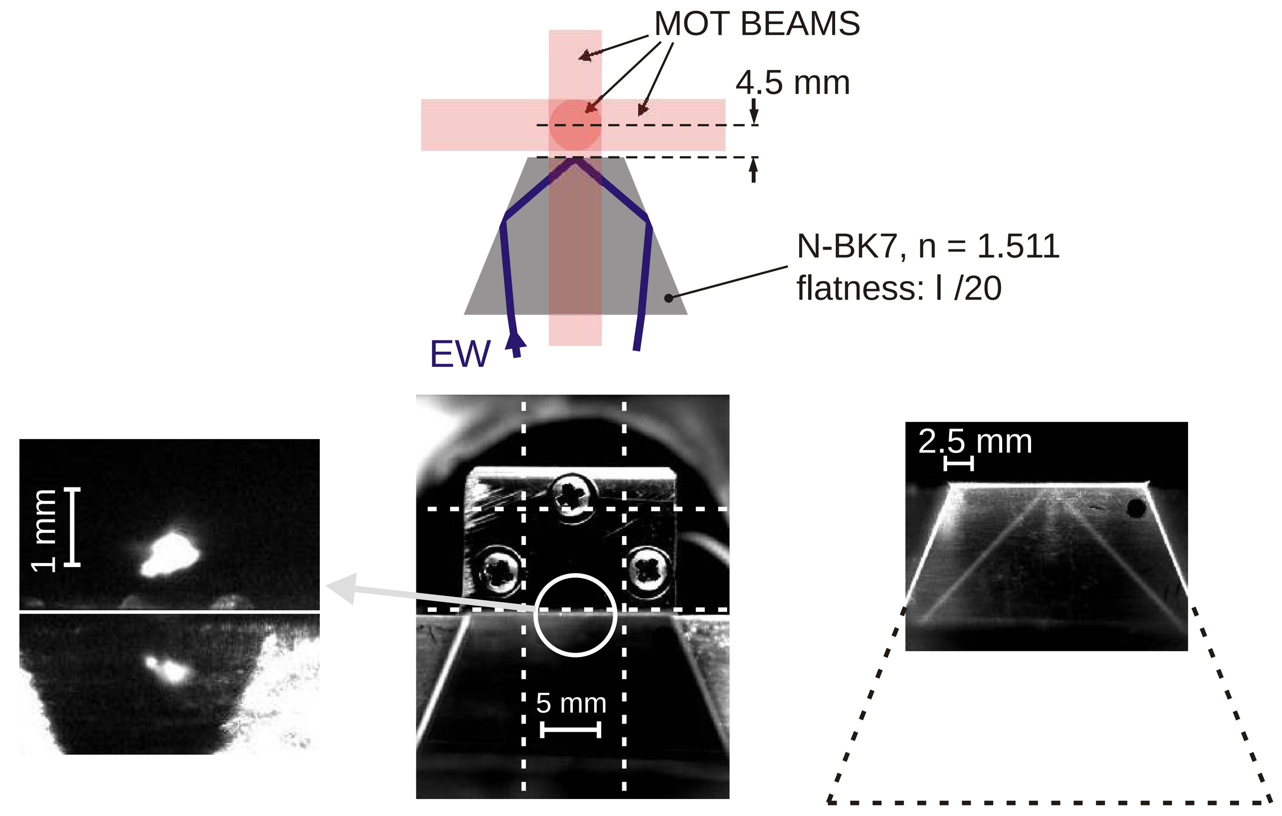
EW intensity

$$U_{vdW} = -\frac{n^2-1}{n^2+1}\frac{1}{64\pi\epsilon_0}\frac{\frac{4}{3}e^2 a_0^2 \cdot 28.2}{z^3}$$

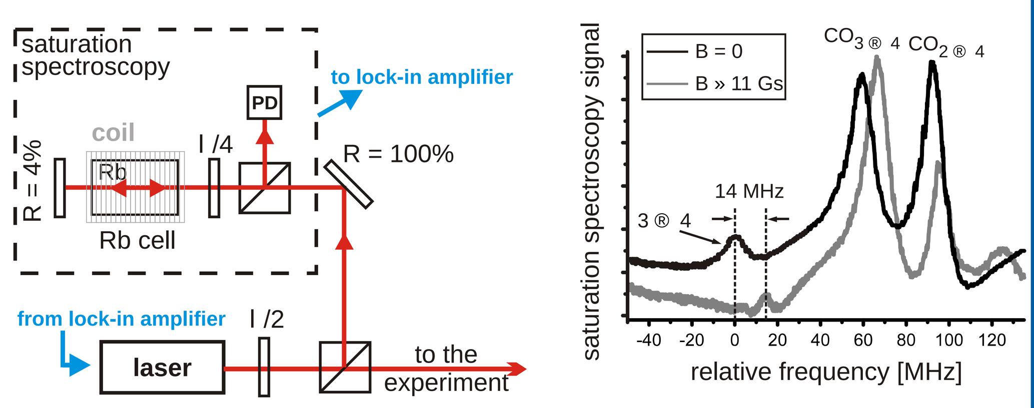
n – index of refraction
a_0 – Bohr radius

EXPERIMENTAL SETUP



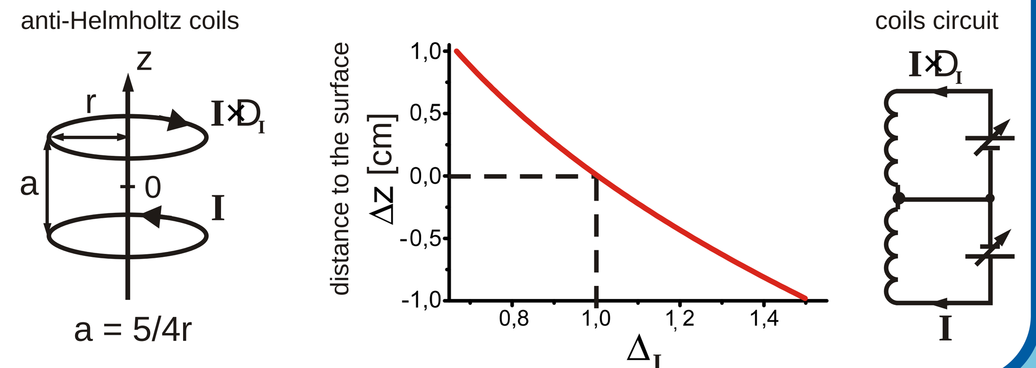


LASER FREQUENCY STABILIZATION

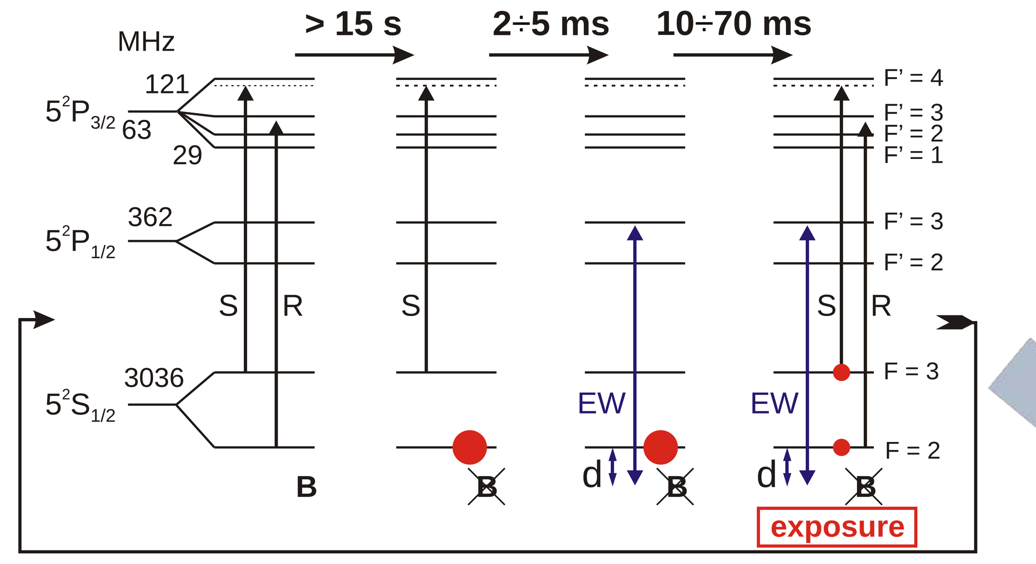


exemplary coil parameters:
length: 82 mm
diameter: 21.75 mm
number of layers: 4
number of turns: 164per layer
wire: DNE 0.5

BRINGING ATOMS CLOSER TO THE PRISM SURFACE

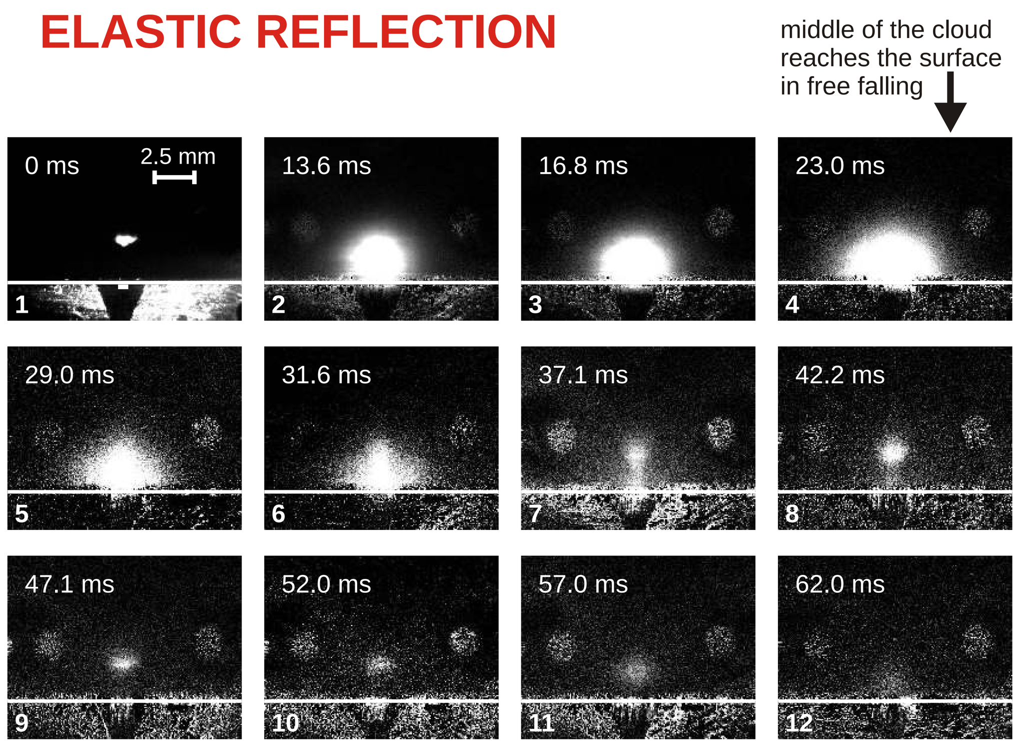


EXPERIMENTAL PROCEDURE (example)



S – cooling laser
R – repumping laser
B – magnetic field
EW – evanescent wave
d – EW detuning

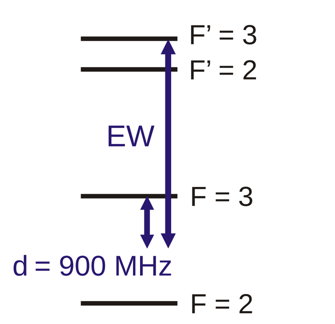
ELASTIC REFLECTION



the width of the white rectangle in the figure 1 corresponds to the gaussian (e^{-1}) diameter of the EW spot

optical mirror parameters:

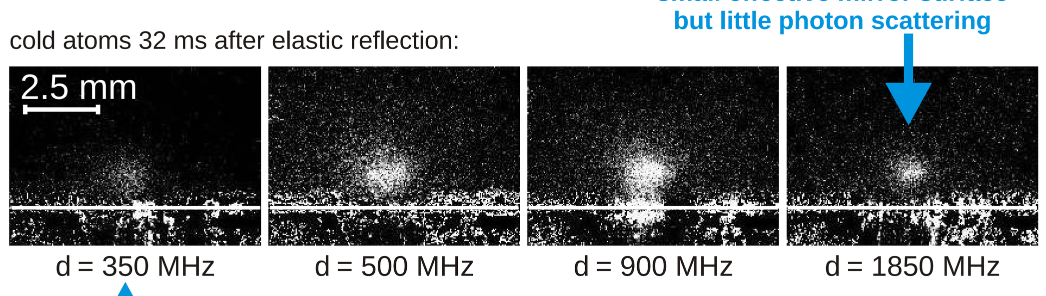
EW beam power: 17.4 mW
EW maximal intensity: 180×10³ W/m²
EW spot mean diameter: 0.39 mm
critical angle: 41.5°
incident angle: 43.0°
penetration depth: 520 nm
polarization: TM



PHOTON SCATTERING

shallow potential, small effective mirror surface but little photon scattering

cold atoms 32 ms after elastic reflection:



deep potential but great photon scattering: atoms may jump to another state and feel only weak repulsive or even attractive potential

photon scattering rate for the (F,m) sublevel:

$$\Gamma_{Fm}^{sp} = \frac{3}{16}\frac{\Gamma^2\lambda^3}{\pi^2\hbar c} I(z) \sum_{F'} \frac{|C_{Fm,F'm}|^2}{(2\pi\,\delta_{FF'})^2}$$

EW detuning in relation to the F ® F' transition

number of scattered photons per one bounce:

$$p_{2m}^{sp} = \int_{-\infty}^{\infty} \Gamma_{2m}^{sp}\, dt$$

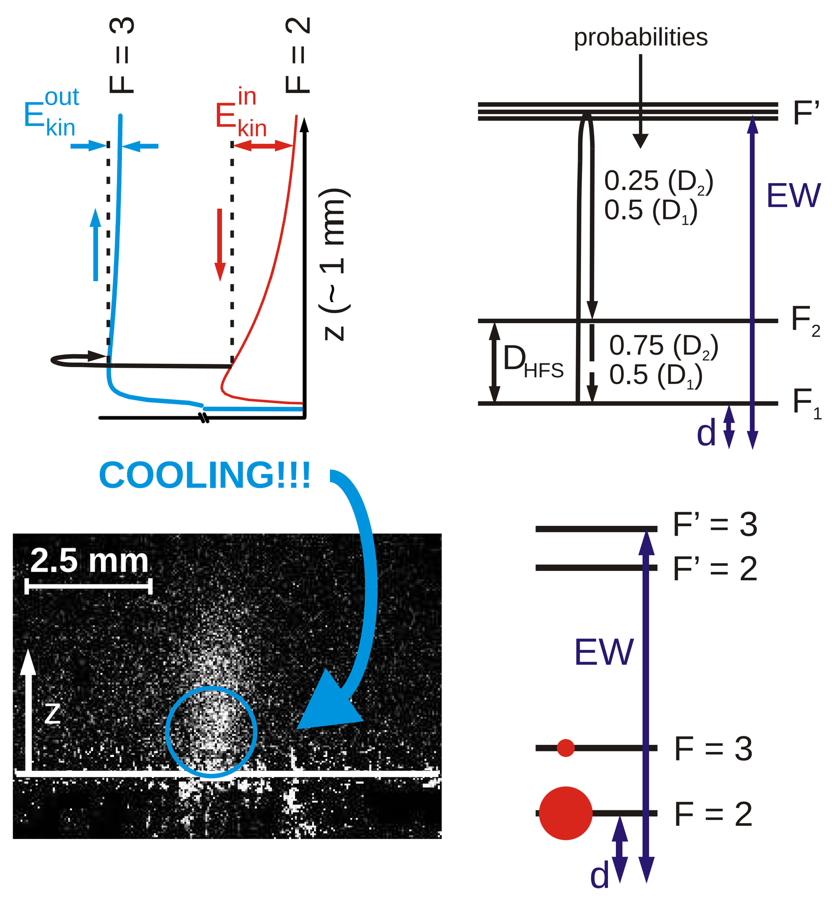
two level approximation:
d – penetration depth
$v_\perp$ – velocity component when reaching the surface

$$p^{sp} = \frac{md}{\hbar}\frac{\Gamma}{\delta} v_\perp$$

» 0.3 @ d = 1850 MHz
» 1.5 @ d = 350 MHz

INELASTIC REFLECTION

photon scattering may be useful...



atoms climb up the **high** mountain but roll down the **small** hill...

cooling efficiency for single succesful inelastic reflection:

$$\frac{\Delta E_\perp}{E_\perp} = \left(\frac{2}{3}\right)\frac{\Delta_{HFS}}{\delta + \Delta_{HFS}} \approx 0.47$$

d = 900 MHz
D_{HFS} = 3036 MHz

some atoms scatter photon before classical turning point...

OUTLOOK

The described optical dipole mirror will be used firstly in two experiments:

1. **off-resonant nondestructive detection of bouncing atoms**
   Additional far-detuned evanescent wave is going to be used to probe changes in the index of refraction caused by the presence of bouncing atoms.
2. **precise measurements of the influence of the dielectric proximity on the atom radiative properties**
   The described setup will not be used as a mirror but rather evanescent wave detector for falling atoms. The weak resonant evanescent wave will allow to measure changes in the optical transition energy and width.

REFERENCES

[1] R. Folman, P. Krüger, J. Schmiedmayer, J. Denschlag, C. Henkel, *Microscopic atom optics: from wires to an atom chip*, Adv. At. Mol. Opt. Phys. **48**, 263 (2002)
[2] J.P. Dowling and J. Gea-Banacloche, Adv. At. Mol. Opt. Phys. **37**, 1 (1996)
R. Grimm, M. Weidemüller, Yu.B. Ovchinnikov, *Optical dipole traps for neutral atoms*, Adv. At. Mol. Opt. Phys. **42**, 95 (2000)
[3] V.I. Balykin, V.S. Letokhov, Yu.B. Ovchinnikov, A.I. Sidorov, *Quantum-State Selective Mirror Reflection of Atoms by Laser Light*, Phys. Rev. Lett. **60**, 2137 (1988)
[4] M.A. Kasevich, D.S. Weiss, S. Chu, *Normal-incidence reflction of slow atoms from an optical evanescent wave*, Opt. Lett. **15**, 607 (1990)
[5] Yu.B. Ovchinnikov, J. Söding, R. Grimm, *Cooling Atoms in Dark Gravitational Laser Traps*, JETP Lett. **61**, 10 (1995)
[6] Yu.B. Ovchinnikov, D.V. Laryushin, V.I. Balykin, V.S. Letokhov, *Cooling of atoms on reection from a surface light wave*, JETP Lett. **62**, 113 (1995)
[7] Yu.B. Ovchinnikov, I. Manek, R. Grimm, *Surface Trap for Cs atoms based on Evanescent-wave Cooling*, Phys. Rev. Lett. **79**, 2225 (1997)
[8] D. Rychtarik, B. Engeser, H.-C. Nägerl, R. Grimm, *Two-dimensional Bose-Einstein condensate in an optical surface trap*, Phys. Rev. Lett. **92**, 173003 (2004)
see also:
J. Söding, R. Grimm, Yu.B. Ovchinnikov, *Gravitational laser trap for atoms with evanescent-wave cooling*, Opt. Commun. **119**, 652 (1995)