Personal notes : Crossed dipole trap

Félix Hoffet[1]
[1] *ICFO – Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, Spain*

When a field $\mathbf{E}$ is incident on an atom with one valence electron, its dipole moment $\mathbf{d}$ is not zero anymore due to force induced by the field on the electron. The polarizability $\alpha(\omega)$ describes how easily the field induces the dipole moment by $\mathbf{d} = \alpha(\omega)\mathbf{E}$, and the potential energy of the induced dipole is given by $V_{\text{dip}} = \mathbf{d} \cdot \mathbf{E}/2$. In a position dependent field, we find that

$$V_{\text{dip}}(\mathbf{r}) = -\frac{\text{Re}(\alpha)}{2\epsilon_0 c} I(\mathbf{r}). \tag{1}$$

The potential energy is shifted via the real part of the polarizability, and this shift corresponds to the atomic counterpart of the phase shift accumulated by the light crossing an atomic medium. Indeed, the dispersion of a medium, describing the accumulated light phase shift, is also linked to $\text{Re}(\alpha)$. This shift in potential energy is also called the AC-Stark shift. The force resulting from this potential is related to the gradient of intensity $\mathbf{F} \propto \nabla V_{\text{dip}} \propto \nabla I(\mathbf{r})$. Therefore, a spatially dependent light intensity can induce a spatial displacement on the atoms. One can use a simple lens to focus a laser beam, resulting in the creation of a potential well allowing to trap atoms. Using this principle, we implement in our experiment a crossed dipole trap consisting of two retroreflected elliptical gaussian beams. They are propagating at a right angle, one in the $\mathbf{x}$ (horizontal) direction and the other in the $\mathbf{y}$ (vertical) direction. The intensity of the horizontal and vertical beams can be expressed as

$$I_h(x,y,z) = \frac{2P_h}{\pi w_y(x) w_z(x)} e^{-2\left(\frac{y^2}{w_y(x)^2} + \frac{z^2}{w_z(x)^2}\right)} \quad \text{and} \quad I_v(x,y,z) = \frac{2P_v}{\pi w_x(y) w_z(y)} e^{-2\left(\frac{x^2}{w_x(y)^2} + \frac{z^2}{w_z(y)^2}\right)} \tag{2}$$

where P_h (P_v) is the power, $w_x(y) = w_{x,0}\sqrt{1 + y^2/y_{R,x}^2}$, $w_y(x) = w_{y,0}\sqrt{1 + x^2/x_{R,y}^2}$ and $w_z(x) = w_{z,0}\sqrt{1 + x^2/x_{R,z}^2}$ are the spot sizes. Here, $x_{R,y} = \pi w_{y,0}^2/\lambda$, $y_{R,x} = \pi w_{x,0}^2/\lambda$ and $x_{R,z} = y_{R,z} = \pi w_{z,0}^2/\lambda$ are the Rayleigh lengths, with λ the wavelength of the beam. The total intensity seen by the atom is simply $I(\mathbf{r}) = I_v(x,y,z) + I_v(x,y,z)$, and we assume that the beams do not interfere with one another. Experimentally, we rotate the polarization of the retroreflected beam to prevent any kind of interference. To estimate the trapping potential, we extract the real part of the polarizability using the ARC package (see : ARC dynamic polarizability calculation), and find a value of $\text{Re}(\alpha) = 2071$ a.u. with the atomic unit 1 a.u. $= 1.65 \cdot 10^{-41}$ SI. The two main transitions that contributes to the polarizability are the D1-line and the D2-line.

To obtain a trap with many atoms, we first load our optical dipole trap from a magneto optical trap (MOT). To do so, we superimpose the crossed dipole trap with the atoms from the MOT. In order for the atoms to fall in the trap, we need the trapping potential to be deeper than the kinetic energy due to the atomic cloud temperature that is around 200 µK. For our experimental implementation, we chose to have larger beam waists in the x and y direction to

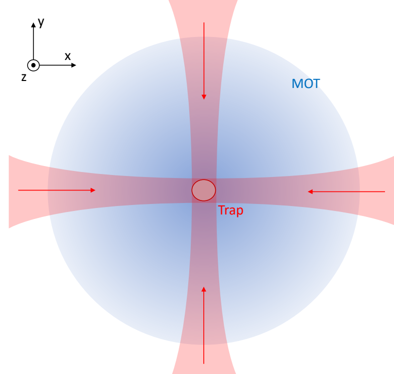

FIG. 1. Illustration of the crossed dipole trap loading. The crossed dipole trap is put on top of the MOT, leading to a flow of atom falling in the center of the crossed dipole trap through the beams. This flow is represented in by the red arrows.

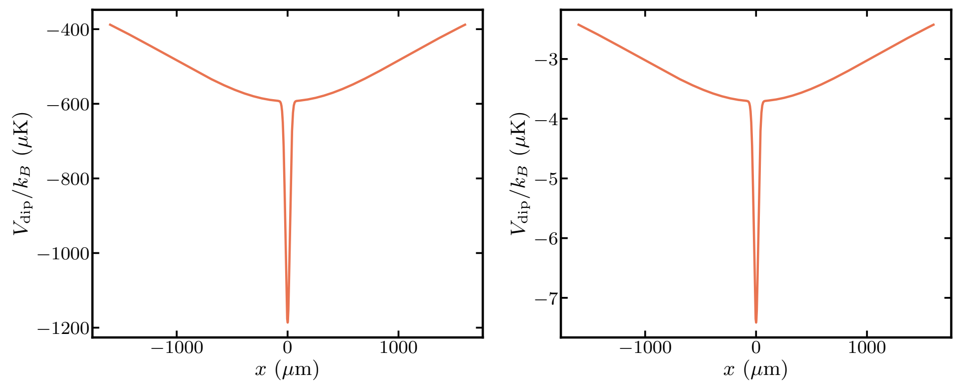

FIG. 2. Potential generated by the crossed dipole draps beams, alongside the x direction. The two figures represent different powers in the beam: $P_v = P_h = 2 \cdot 800\,\mathrm{mW}$ (left) and $P_v = P_h = 2 \cdot 10\,\mathrm{mW}$ (right). We observe the large potential well that drives the atoms to the small and deep central potential well generated by the intersection of the two beams.

create a cloud that has a pancake size. The values are $w_{x,0} = w_{y,0} = 40\,\mu\mathrm{m}$ and $w_{z,0} = 20\,\mu\mathrm{m}$. To load the dipole trap, we shine $P_v = P_h = 2 \cdot 800\,\mathrm{mW}$, where the factor two accounts for the retroreflection.

We plot in Fig. 2 (left) the potential alongside the x-axis during the loading, with a maximum trap depth of $V_0 = 1179\,\mu\mathrm{K}$. We observe this typical shape of a first large well, used to direct atoms to the thinner and deeper well located at the intersection of the two beams.

To estimate the size of the atomic cloud, we assume that the atoms see a harmonic potential

$$V_{\mathrm{dip}} \sim V_0 + \frac{1}{2} m \left(\omega_x^2 x^2 + \omega_y^2 y^2 + \omega_z^2 z^2 \right) \tag{3}$$

which is a valid assumption at the center of the trap. The trapping frequencies of this potential are given by $\omega_i = \sqrt{\omega_{i,h}^2 + \omega_{i,v}^2}$, with

$$(\omega_{x,h}, \omega_{y,h}, \omega_{z,h}) = \sqrt{-\frac{V_{0,h}}{m}} \left(\sqrt{\frac{1}{x_{R,y}^2} + \frac{1}{x_{R,z}^2}}, w_{y,0}, w_{z,0} \right) \tag{4}$$

and similarly for the vertical beam

$$(\omega_{x,v}, \omega_{y,v}, \omega_{z,v}) = \sqrt{-\frac{V_{0,v}}{m}} \left(w_{x,0}, \sqrt{\frac{1}{y_{R,x}^2} + \frac{1}{y_{R,z}^2}}, w_{z,0} \right) \tag{5}$$

where m is the mass of one Rubidium-87 atom. In the steady state, the density follows a gaussian distribution in the three directions, with standard deviation

$$\sigma_i = \sqrt{\frac{k_B T}{m \omega_i^2}}. \tag{6}$$

We see here that our cloud size is influenced by the temperature of the sample. Therefore, after perfoming Raman cooling in our atomic cloud, leading to a temperature of $T = 2\,\mu\mathrm{K}$, we reduce the power in the beams to $P_v = P_h = 2 \cdot 10\,\mathrm{mW}$ leading to the potential plotted in Fig. 2 (right). This leads to a pancake cloud with $34\,\mu\mathrm{m}$ FWHM in the x-y plane and $12\,\mu\mathrm{m}$ FWHM in the z direction.