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Физика волновых процессов и радиотехнические системы

Numerical simulations of the Ioffe-Pritchard trap for cold dressed atoms

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An Ioffe-Pritchard trap for cold dressed atoms is studied by numerical simulations. It is shown that the potential generated by static and alternating currents provides trapping of two sorts of cold dressed atoms. The studied topology is controlled with the frequency and static currents, and it is for study of the atom collision effects and the entanglement of the atoms after a collision.

Introduction

Recently, increased attention has been paid to handling of cold atoms by combinations of the RF and static fields described with the dressed atom formalism that was proposed at the end of 60s [1]. A new wave of interest in this approach was initiated by several published theoretical and experimental papers on this effect that is considered promising for quantum interferometry and quantum computing [2]-[6]. For example, in [4], a modified formula for the trapping potential is derived and in [6] multifrequency RF excitation is considered for trapping atoms with different states in a lattice structure.

The formula for the effective trapping potential from [4] was used for analytical simulation of the Ioffe-Pritchard trap fed by the radio frequency (RF) and static (DC) currents in [7], [8]. The static magnetic field was calculated with the analytical formulas given in the references. The RF field was computed with the assumption that for trap sizes essentially smaller than the RF wavelength, the quasi-static approximation is acceptable.

Here, we show some new results derived by numerical simulations performed with the software tool AMPERES that handles both DC and alternating currents [9]. It is found that the analytical and numerical simulations agree well. The formation of the RF induced splitting of the effective potential is shown. Inside the trap, the minima and maxima are formed, and they are controlled by the frequency and DC currents. After loading of this trap, the potential can be transformed back into a one-minimum again to provide the collisions of these atoms and to enable a study of the possible entanglement of these atoms.

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1. Numerical simulations of the effective potential

The studied trap is shown in Fig. 1. The bars carry DC currents only. The currents are opposite to each other on neighbouring bars. The rings support DC and RF currents of opposite direction and phase, correspondingly. All conductors have finite diameters.

To compute the fields for a more realistic trap than in [7], the commercially available software tool AMPERES was used. The program is based on the boundary integral equation method that is rather immune towards numerical errors. The effective potential is computed according to a formula from [4]. This formula was used in [7] and [8] as well for analytical computations of an RF controllable Ioffe-Pritchard trap for cold dressed atoms.

At first the Ioffe-Pritchard trap with the DC-currents $\left(\left|I_{DC}^{bar,i}\right| = \left|I_{DC}^{ring,j}\right| = 0.5\,A\right)$ is simulated. The trap has four bars of diameter $d_b = 1$ mm, and two rings of diameter $R = 5\ mm$. The wire diameter of the rings is $d_r = 1$ mm and they are placed at a distance of $\Delta = 10\ mm$.

Fig. 2 shows the potential distribution on the plane $A - A'$ (see Fig. 1). The formed classical minimum is seen at the centre of the trap. Fig. 3 shows the distribution of the potential on the plane xy derived at the centre of the trap ($z = 0$).

Fig. 4 shows one of the simulations for the Ioffe−Pritchard trap loaded by DC currents and RF currents of opposite

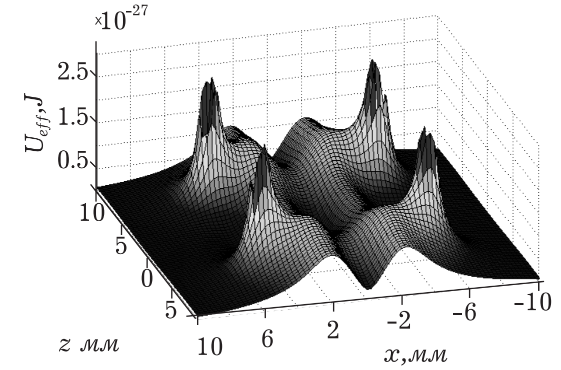

Fig. 1. 3D-view of the Ioffe-Pritchard trap (a) and its cross-section (b)

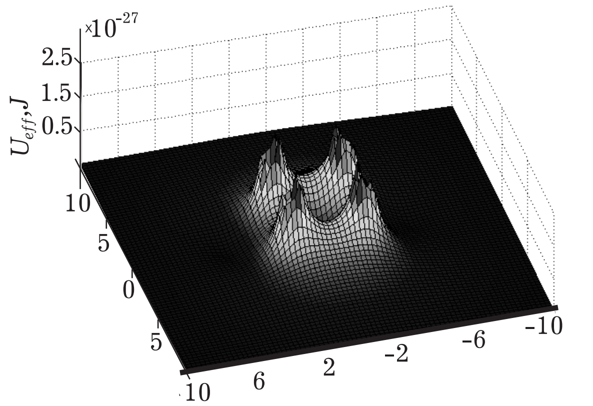

Fig. 2. Plot of the DC induced effective potential computed by AMPERES in the coordinate system (x_a, z_a) associated with the plane $A - A'$

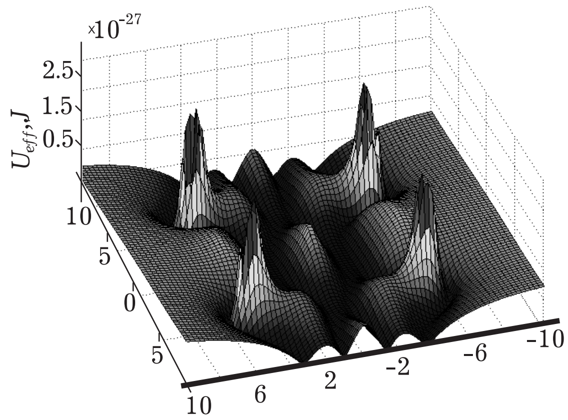

Fig. 3. Plot of the DC induced effective potential computed by AMPERES in the coordinate system (x, y) at $z = 0$

phase $\left(\left|I_{DC}^{bar,i}\right| = \left|I_{DC}^{ring,j}\right| = 0.5\,A, \left|I_{RF}^{ring,j}\right| = 0.1\,A, F = 0.6\,MHz\right)$. The shown plot is calculated on the surface $A - A'$ (see Fig. 1b). AMPERES is used to compute two sets of data for the DC and RF excitations. Then, the potential U_{eff} is computed with Matlab according to the formula originally published in

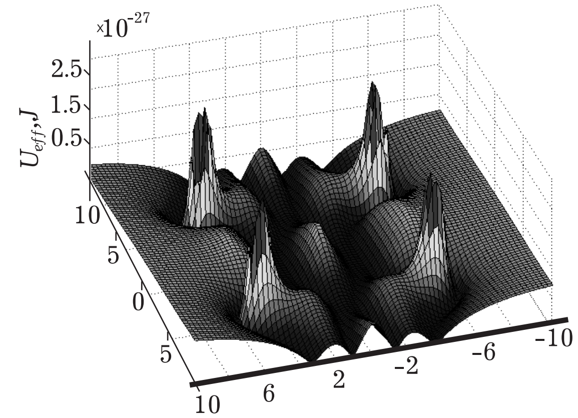

Fig. 4. Plot of the RF induced effective potential computed by AMPERES in the coordinate system (x_a, z_a) associated with the plane $A - A'$

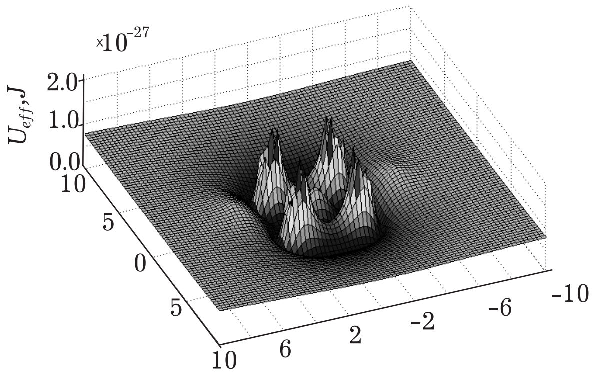

Fig. 5. Plot of the RF induced effective potential computed by AMPERES in the coordinate system (x, y) at $z = 0$

[4]. The corresponding potential distribution on the plane xy at the centre of the trap ($z = 0$) is shown in Fig. 5.

It is seen that close to the bars, the minima have started to form (Fig. 4) that correspond to the results derived analytically in [7]. On the central line with $x = y = 0$ the RF induced local maximum is formed. Its magnitude is the highest at the centre of the trap $z = 0$ in spite that the DC and RF fields are minimal here. It is explained by the quantum mechanical origin of this maximum. The dressed atoms are interacting with the photons and not with the classical RF field that is zero at the centre of the trap. Further transformation of the RF formed topology is achieved by increase of the frequency up to 0.8-0.9 MHz and decrease of the bars' DC currents to 0.1 A. The weak field seeking atoms $(m_F = 2)$ concentrate around the bars of this trap. Other atoms with $m_F = 1$ can be collected at the centre of the trap near the relative maximum of the effective potential. This multi-minimum potential can be transformed into the one-minimum potential again (Fig. 2), and the collision of atoms occurs. Then it can excite the entanglement state of some atoms that can be studied by conventional techniques.

Conclusions

Numerical computations of the effective RF controllable potential in the Ioffe-Pritchard trap for cold dressed atoms have been performed. An effective multi-minimum potential is induced with the static magnetic and radio-frequency fields. The spatial topology of the potential is controlled by the frequency and the static currents. Changes in the currents and frequency allow the splitting of the atom clouds around the trap's bars and the transformation of this topology back into a single-minimum potential. The derived results are interesting in the study of collisions of cold atom clouds that contain atoms with different quantum states.

References

1. S. Haroche and C. Cohen-Tannoudji, J. Physque. 30, (1969) 125.
2. O. Zobay and B. M. Garraway, Phys. Rev. Lett. 86 (2001) 117.
3. Y. Colombe et al., arXiv: quant-ph/0403006 v1 (2004).
4. T. Schumm et al., Nature 1 (2005) 57.
5. I. Lesanovsky et al., arXiv: physics/0510076 v2 (2006).
6. Ph.W. Courteille et al., arXiv: quant-ph/0512061 v2 (2006).
7. G.A. Kouzaev and K.J. Sand, arXiv: cond-mat/0602210.
8. G.A. Kouzaev and K.J. Sand, Modern Physics Lett. B, (Submitted 2006).
9. AMPERES. Quick Start Guide (Integrated Engineering Software Inc., Winnipeg 2005).