Using optical nanofibres to mediate cold atom interactions

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Abstract. We discuss several recent advances related to optical nanofibres in cold atom systems, including two-colour dipole trap optimisation using an in-loop stochastic artificial neural network machine learner, upper bound limitations on Rydberg atom excitation due to localised ion formation, spectral lineshapes arising from the high intensity evanescent fields, and two-photon processes mediated via the evanescent field of the optical nanofibre.

1 Introduction

Optical nanofibres – very thin, tapered optical fibres where the waist diameter is less than the propagating light wavelength – have been shown to be very useful tools for atom-light interactions [1,2]. Their small size and relative ease of integration into optical fibre-based experimental setups, in addition to their minimal perturbation on magneto-optically trapped cold atoms, have ensured their adoption into cold atom physics. Here, we will discuss some recent applications of optical nanofibres to manipulate, trap, and control cold ^{87}Rb atoms in ground or Rydberg states. We will present some recent experimental and theoretical results related to the interactions between the atoms and the optical nanofibre field and introduce some of the limitations observed.

2 Details

We have performed several experimental and theoretical studies related to ground state and excited state alkali atom interactions with the evanescent light fields of optical nanofibres. These allow us to explore some hard-to-access transitions in the alkali atoms, such as quadrupole excitations [3,4], and to determine the influence of the dielectric nanofibre on spectral emissions and lineshapes [5-7]. Two specific examples of studies that we have completed are detailed in the following.

2.1. Machine learner optimisation of fibre-based dipole traps

One example of an application of optical nanofibres is the confinement of cold alkali atoms in two-color fibre-based traps [8]. The efficiency of these traps depends on several factors, such as the wavelength and intensity of light in the fibre's evanescent field, and the preloading laser-cooling process. Typically, only one or no atom is confined per trapping site. Increasing the number of filled trapping sites, thence the optical depth of the system, is desirable and relies on improving the trapping efficiency. We have used a machine learner that optimizes the absorption signal of a probe beam, hence the optical depth, by exploring a parameter space related to initial laser-cooling parameters. Through this process, we increased the number of atoms trapped in the fibre traps by 50% and the optical depth by 70% [9].

2.2 Rydberg atom generation near optical nanofibres

A second application is the creation of Rydberg atoms, which are highly excited neutral atoms, via the evanescent field [10]. As a first step, we have explored the upper limitations on the Rydberg level, n, that can be achieved for S and D state atoms due to dielectric interactions and ion formation. We envision that through judicious selection of the Rydberg level and by improving the trapping efficiency of ground state atoms in fibre-based traps via machine learning as mentioned above, we can explore novel schemes for generating 1D chains of Rydberg atoms near optical nanofibres.

3 Conclusion

In conclusion, we have discussed several recent theoretical and experimental advances in atom and optical nanofibre integrated systems. In future work, a combination of several techniques that we have developed will be used to create 1D chains of Rydberg atoms next to optical nanofibres to study many-body physics and to further explore nonlinear processes such as four-wave mixing.

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References

1. M.J. Morrissey, K. Deasy, M. Frawley, R. Kumar, E. Prel, L. Russell, V.G. Truong, S. Nic Chormaic, Sensors **13**, 10449 (2013)
2. P. Lodahl, S. Mahmodian, S. Stobbe, A. Rauschenbeutel, P. Schneeweiss, J. Volz, H. Pichler, P. Zoller, Nature **541**, 473 (2017)
3. F. Le Kien, T. Ray, T. Nieddu, T. Busch, S. Nic Chormaic, Phys. Rev. A **97**, 013821 (2018)
4. T. Ray, R.K. Gupta, V. Gokhroo, J.L. Everett, T. Nieddu, K.S. Rajasree, S. Nic Chormaic, New J. Phys. **22**, 062001 (2020)
5. E. Stourm, M. Lepers, J. Robert, S. Nic Chormaic, K. Mølmer, E. Brion, Phys. Rev. A **101**, 052508 (2020)
6. F. Le Kien, D.F. Kornovan, S. Nic Chormaic, T. Busch, Phys. Rev. A **105**, 042817 (2022)
7. V. Gokhroo, F. Le Kien, S. Nic Chormaic, J. Phys. B : At. Mol. Opt. Phys. (accepted 2022)
8. F. Le Kien, V.I. Balykin, K. Hakuta, Phys. Rev. A **70**, 063403 (2004)
9. R.K. Gupta, J.L. Everett, A.D. Tranter, R. Henke, V. Gokhroo, P.K. Lam, S. Nic Chormaic, AVS Quant. Sci. (accepted 2022)
10. K.S. Rajasree, T. Ray, K. Karlsson, J.L. Everett, S. Nic Chormaic, Phys. Rev. Res. **2**, 012038(R) (2020)