Periodic Density Patterns in Dipolar Bose-Einstein Condensates Trapped in Deep Optical Lattice

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The Bose-Einstein condensates (BEC) of dipolar atoms or molecules loaded into optical lattices (OL) have been the focus of research work for the past decade, starting from the theoretical analysis of basic properties of such condensates, followed by the analysis of quantum phases, various textures, and the suppression of the quantum collapse (fall onto an attractive center) in them. Structured ground states and supersolidity of dipolar gases, as well as the rotonic dispersion relation, were discussed theoretically but still await experimental confirmation. Experimentally, the first effects of dipolar interactions in quantum gases were observed in the BEC of 52Cr atoms [1]. A condensate of 164Dy atoms was recently created too [2], which provides an even stronger dipole-dipole (DD) interaction than 52Cr. In addition to that, the creation of dipolar BEC is expected in erbium [3] and in gases of molecules carrying electric dipole moments [4]. A powerful tool that allows one to control dynamical effects in the dipolar BEC, such as the onset of collapse, is the use of the Feshbach resonance for tuning the strength of contact interactions between atoms, which compete with their long-range DD interactions. The results obtained in this field have been summarized in a recent review [5].

The objective of this work is to demonstrate that stable periodic density patterns are possible in BEC with long-range dipole-dipole (DD) inter-atomic interactions. While the state of the trapped condensate may obviously feature the same periodicity as the underlying lattice [we call it the continuous-wave (cw) state], here we report stable density waves in the form of double- and triple- period patterns (DPPs and TPPs) in the dipolar BEC loaded into a deep OL potential. We consider all possible combinations of the repulsive contact (RC) or attractive contact (AC) and repulsive DD (RDD) or attractive DD (ADD) interactions, and demonstrate that unstaggered (regular) DPPs and TPPs have their stability regions in the RC+RDD case, provided that the sufficiently strong long-range DD repulsion can stabilize the DPPs and TPPs [6,7].

The analysis reveals that the multiple-period patterns emerge when the corresponding modulational instability of the cw sets in; i.e., the respective perturbations seed the creation of the patterns. The TPP's stability area is found to be much larger than that of the DPP, and the calculation of the free-energy density demonstrates that the TPP realizes a well-pronounced energy minimum, in comparison with the cw and DPP states. When the TPPs are unstable, the DD interactions of either sign significantly inhibit the instability, suggesting that even unstable TPPs may be observed in the experiment [7].

References

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