High-resolution imaging of dysprosium Bose-Einstein condensates

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Application Note

Introduction

In the field of ultracold atomic physics, two main tools are needed: control of internal and external properties and a very good detection of the atomic cloud. Technological and scientific progress has enabled the possibility of high-resolution imaging techniques with sensitivities at the single atom limit. For our experiments we use a microscope objective with a numerical aperture of 0.32 and an EMCCD camera (Andor iXon3 DU897-ECS-EXF).

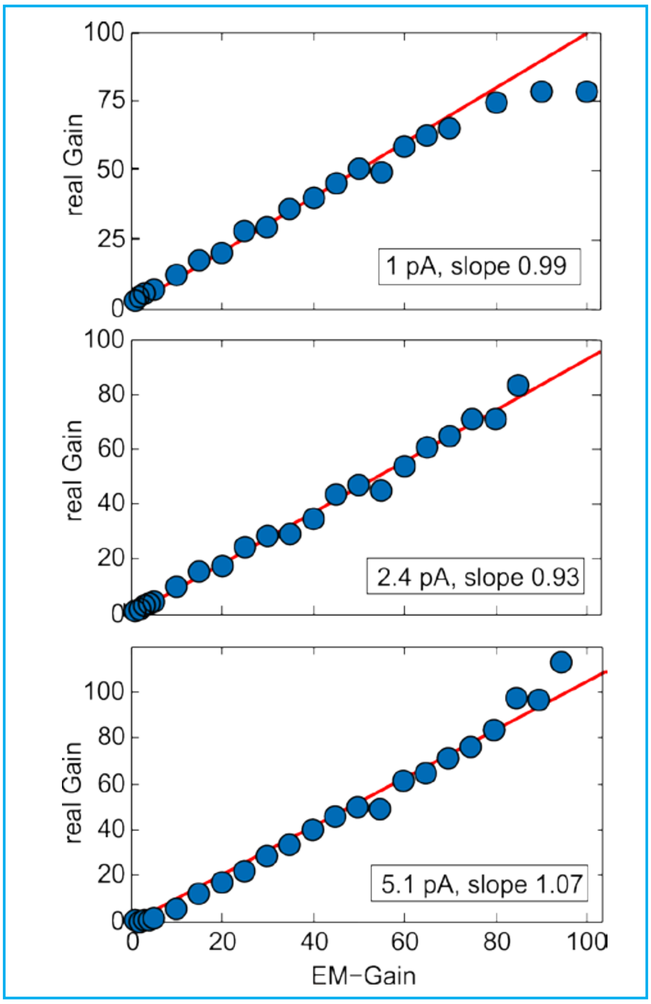

Figure 1: EM gain for three different preamplifiers. The real gain is shown as relative gain to EM gain = 1. We could verify with our methods the linearity of the EM gain.

Characterization of the EMCCD camera

We performed measurements on crucial characteristics of the camera in the framework of a bachelor thesis. For all our tests we used monochromatic coherent blue light at 421 nm with a Gaussian shaped beam profile. The beam intensity was well known and any used attenuators were calibrated. First, we checked the EM gain for linearity by assuming unity EM gain means unity real gain. The results are shown in Figure 1 for the three possible preamplifier modes (pA). We verified the real gain to be very close to the real gain, by showing a linear fit with slopes close to one.

Second, by assuming the CCD sensitivity of the pA to be correct, we determined the shot noise of the iXon3. We imaged the well-calibrated beam more than 100 times and determined the mean photon number N and the variance ΔN^2 of each pixel. In Figure 2, we show the variance against the mean number and observe a linear slope close to 2, in agreement with EMCCD technology that increases the noise by a factor of $\sqrt{2}$. The mean slope of many repetitions is 2.07.

Third, with the same data, we could extract the quantum efficiency (QE). We obtained a QE of 83(5)% at 421 nm.

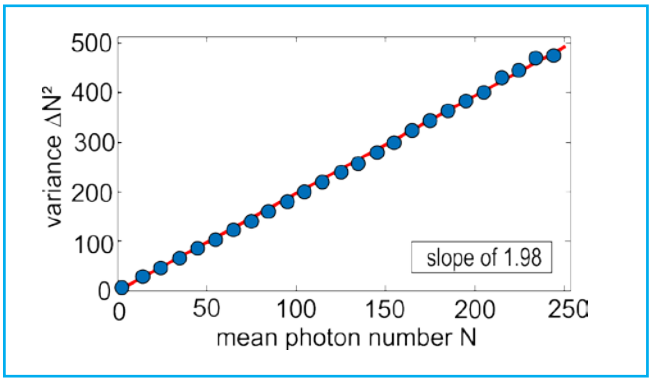

Figure 2: Measuring the photon shot noise of the EMCCD camera. We use a well-calibrated Gaussian shaped beam to extract the mean photon number per pixel N and measure its variance ΔN^2. We can verify the typical slope of 2 for EMCCD technology.

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Experiments

We prepare a dysprosium Bose-Einstein condensate with typically 15,000 atoms. We detect the atoms with in situ phase-contrast polarization imaging [1]. This technique relies on the dispersive phase shift of atoms instead of direct absorption.

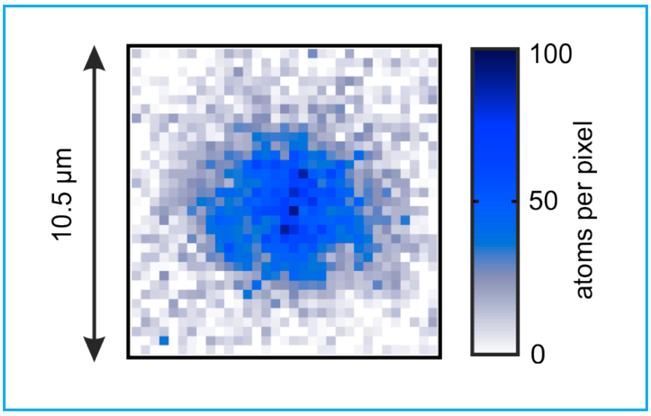

Figure 3: Single-shot in situ image of a dysprosium Bose-Einstein condensate. The optical magnification is 50 and the field of view is here 10.5 µm x 10.5 µm.

We use off-resonant light (35 linewidth red detuned) near the optical transition at 421 nm. By using linear polarized light, the dysprosium atoms show a strong optical rotation. The atomic plane is imaged through a commercial objective and magnified by a factor of 50. The light is guided through a linear polarizer to the EMCCD camera. Finally, we achieve images as shown in Figure 3 and in Reference [2].

References

[1] C. C: Bradley, C. A. Sackett, R. G. Hulet, ‘Bose-Einstein Condensation of Lithium: Observation of Limited Condensate Number’, Phys. Rev. Lett. 78, 985 (1997)

[2] H. Kadau, M. Schmitt, M. Wenzel, C. Wink, T. Maier, I. Ferrier-Barbut, T. Pfau, ‚Observing the Rosensweig instability of a quantum ferrofluid‘, arXiv:1508.05007 (2015)

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