Optical manipulation and study of single gold nanoparticles in solution

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Title: Optical manipulation and study of single gold nanoparticles in solution
Date: 2012-05-10

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PROEFSCHRIFT

ter verkrijging van
de graad van Doctor aan de Universiteit Leiden,
op gezag van Rector Magnificus prof. mr. P.F. van der Heijden,
volgens besluit van het College voor Promoties
te verdedigen op donderdag 10 mei 2012
klokke 15.00 uur

door

Paul Victor Ruijgrok

geboren te Ubbergen, Nederland

in 1981

Promotiecommissie:

Promotor:	Prof. Dr. M. A. G. J. Orrit	(Universiteit Leiden)
Copromotor:	Dr. P. Zijlstra	(Universiteit Leiden)
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	Prof. Dr. E. J. J. Groenen	(Universiteit Leiden)

The work reported in this thesis was carried out at the 'Leids Instituut voor Onderzoek in de Natuurkunde (LION)' and is part of the research program of the 'Stichting voor Fundamenteel onderzoek der Materie (FOM)'.

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Casimir PhD Series, Delft-Leiden, 2012-10
ISBN : 978-90-8593-122-5

voor mijn ouders

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Preface

This thesis reflects four years of research in the MoNOS group at the physics institute in Leiden on the optical trapping of gold nanoparticles, in particular on the use of an optical trap to study single gold nanoparticles in a homogeneous liquid environment.

I started this project with the design and construction of an optical trap, and its integration with the pulsed laser system and confocal microscopy setup already present in the lab, under the guidance of dr. Anna Tchebotareva. During the initial period of construction of the setup we had to wait for new equipment to arrive. We decided to use this time to improve the sensitivity of an optical technique to detect gold nanoparticles. In this technique, a small object that absorbs light can be detected through the refractive effect of the heat that is released in its environment. This technique had been known for many years in analytical chemistry and had been reinvented for single particle detection in far-field optical microscopy by Michel Orrit and colleagues in 2002 in Bordeaux. Since then, the technique had been steadily improved in sensitivity and has been applied in a growing number of applications. Based on recent experiments using photothermal detection in the group in Leiden, we had ideas to significantly improve the signal-to-noise ever further. Our hope was that we could not just detect even smaller gold nanoparticles, but that we would be able to detect single organic dye molecules. With dr. Alexander Gaiduk, we set out to see whether this could be done. After a systematic optimization of every part of the experiment, we managed to obtain the expected improvement in signal-to-noise ratio, as we will describe in detail in Chapter 2. The first experiments on organic molecules were not immediately successful. As the experiment had taken much more time than the originally scheduled two weeks, we decided to stop the experiment on the current setup. Alexander Gaiduk would build a new setup in an adjacent lab, guided by the experience obtained in our experiment. When that setup was finally in working order –and with the help of the newly arrived PhD student Mustafa Yorulmaz– he could continue the trials on organic molecules and they finally succeeded to detect a single non-fluorescent molecule at room temperature, a challenge that had been open for 20 years.

When all the equipment had finally arrived in working order, we continued work on the optical trap, with the help of the newly arrived dr. Peter Zijlstra. Since there was no experience in optical trapping of metal nanoparticles in Leiden, this was not an easy task. Many days were spent in the lab before we finally realized how we could achieve stable trapping of single nanoparticles. During the struggle to optimize the trap, we developed new methods to characterize particles in the trap, based on our previously gathered expertise on methods to characterize particles immobilized on a substrate. When the optical trap finally worked properly, this provided us with unique possibilities to characterize the trapped particle, as we will describe in Chapter 3. During the construction of the trap, we embraced the opportunity to work on gold nanorods, gold nanoparticles with exciting new possibilities that could be synthesized in the Leiden lab by the expertise brought by Peter Zijlstra. Throughout the remainder of the PhD project, we have used both gold nanospheres and nanorods, taking advantage of their different properties in ways most suitable to the requirements of the various experiments.

With a working optical trap and the methods to characterize trapped particles, we could finally start exploring the properties of the nanoparticle in an homogeneous liquid environment. We decided to study the acoustic vibrations of the gold nanoparticles, as had previously been done in the group for particles immobilized on a glass substrate. This experiment involved a complex pulsed laser setup, and required the co-localization of three or more highly focused optical beams. With the optical trap working properly, and all the experience gained in the process, this turned out to be not too great a challenge. The results of this experiment and the surprising finding about the damping of the acoustic vibration can be found in chapter 6.