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PROJECT FINAL REPORT

Grant Agreement number:309672

Project acronym: NEMI

Project title:Scanning Neutral Helium Microscopy: A novel tool for fast, nondestructive characterization of mechanical parameters for nanostructured coatings

Funding Scheme:NMP.2012.1.4-3

Period covered: from 01.03.2015 to 31.08.2016

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Project website Fehler! Textmarke nicht definiert. **address: http://org.uib.no/nemi**

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[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.

Executive Summary (max 1 page)

The majority of failures in pattern replication processes are caused by wear of forming and forging master tools. Tribology is the science applied for lowering the wear by developing advanced (nanostructured) coatings. However, even these coatings are subject to wear that manifest itself as changes in the mechanical properties of the master tool in the form of fractures, roughness changes (adhesion) or deformation of the 3D shape. Hence a careful examination of the surface structure is essential for validating the functionality of a master tool. Ideally by applying a fast, reliable measurement, which determines the first wear before any faulty replication takes place. No such method exists at present for nanoscale structures: Scanning probe microscopy is generally slow and not suitable for the high aspect ratio structures often present in forming and forging tools. Scanning electron and helium ion microscopy offer alternatives. However both beams penetrate into the material, which limits the accuracy, the beam energy can cause surface damage and there may be image distortions due to charging effects.

The main aim of the NEMI project was to develop a new microscope instrument based on neutral helium atoms. This new technique, which we have labelled NEMI (short for NEutral Microscopy) is strictly surface sensitive with no penetration into the bulk (the atoms interact with the outermost electronic layer on the surface). The energy of the atoms is less than 0.1 eV, 4-6 order of magnitudes less than typical electron and helium ion energies. The big limitation in helium microscopy up till now has been that existing helium detectors have had a much too low detection rate (detecting at the best only a few out of 1.000.000 atoms). A major sub-aim of the project as an absolutely crucial requirement for a NEMI microscope was therefore to develop a better helium detector. Because this was deemed such high risk two partners: University of Cambridge (CAM) and SME partner MB-Scientific AB(MB) were working on this following different methods. In the end, both partners managed to make detectors with an efficiency of the order of 0.01 - four orders of magnitude better than existing state of the art detectors. Using the new detectors helium microscopy images were successfully obtained using two different types of helium microscopes: A focussed beam microscope at the University of Bergen (UiB) and a so called pinhole microscope at CAM. Images with resolutions on the micron scale were obtained. The CAM instrument was used to produce the first images of a polymer sample - a Nanoimprint sample from SME partner Nil Technology APS (NILT).

Further results includes: i) A 3D self calibration algorithm developed by the Royal Institute of Technology (KTH). This is a very versatile tool that can be used with a range of other microscopy instruments and production tools, and is receiving considerable interest from industry. ii) A first focussing mirror for helium atoms using graphene/Ru on laser polished fused silica parabolic lenses developed by University Autonoma de Madrid (UAM) and iii) breakthroughs in the production for SME partners NILT and Winther Mould Technology (KW), obtained through metrology investigations by the DanishNational l Metrology institute (DFM): KW can now produce 50% more samples before the mould needs to be changed and NILT is launching a new antireflection product. Finally iv) the third SME partner MB is planning to start a production of neutral helium microscopes.

A total of three patent applications, 14 papers accepted or published in peer reviewed journals and 9 papers in preparations have resulted from this project.

Summary Description of Project Context and objectives (max 4 pages)

The main aim of the NEMI project was to make a running neutral helium microscope. At the end of the project we managed to take helium microscopy images using two different types of helium microscopes: A focussed beam microscope at the University of Bergen (UiB) and a so called pinhole microscope (CAM). Images with resolutions on the micron scale were obtained. The CAM instrument was used to produce the first images of a polymer sample - a nanoimprint sample from SME partner NILT which can be seen in figure 1. The NEMI technique can also be used to investigate porous samples in transmission. A transmission image of a test sample can be seen in figure 2

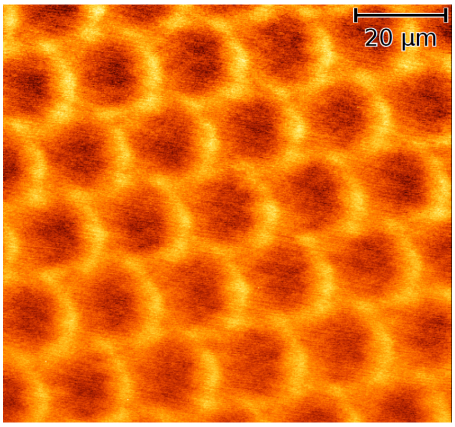


Figure 1: Neutral Helium Microscopy Image of a polymer sample - a Nanoimprint sample from SME partner NILT which can be seen in figure 1. The images was obtained by scanning the sample in steps of 100 nm and measure the reflected intensity at an angle of 45° relative to the incident beam. Plotted is the reflected helium intensity with artificial colouring. Publication in preparation.

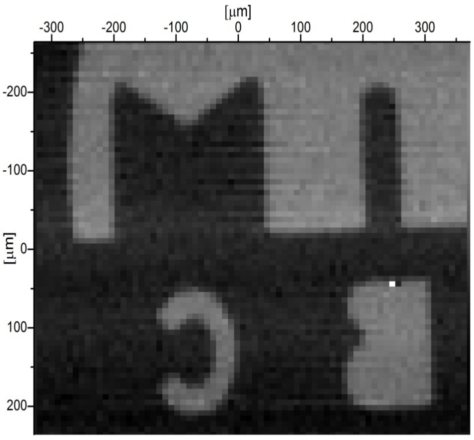


Figure 2: Nemi transmission Image of a test sample. Plotted is the transmitted helium intensity with artificial grey scale colouring. The focussed spot size (image resolution) is about 3 micron. The image step size is 5 micron.

The basic idea in a neutral helium microscope is that the beam is created in a supersonic expansion. The central part of the beam is then selected by a (micro) skimmer and either further collimated with a small aperture to create a small spot on the sample (pinhole setup) or focussed onto the sample using a focussing element i.e. a zoneplate or a focussing mirror. Figure 3 shows a picture of the neutral helium microscope at partner UiB.

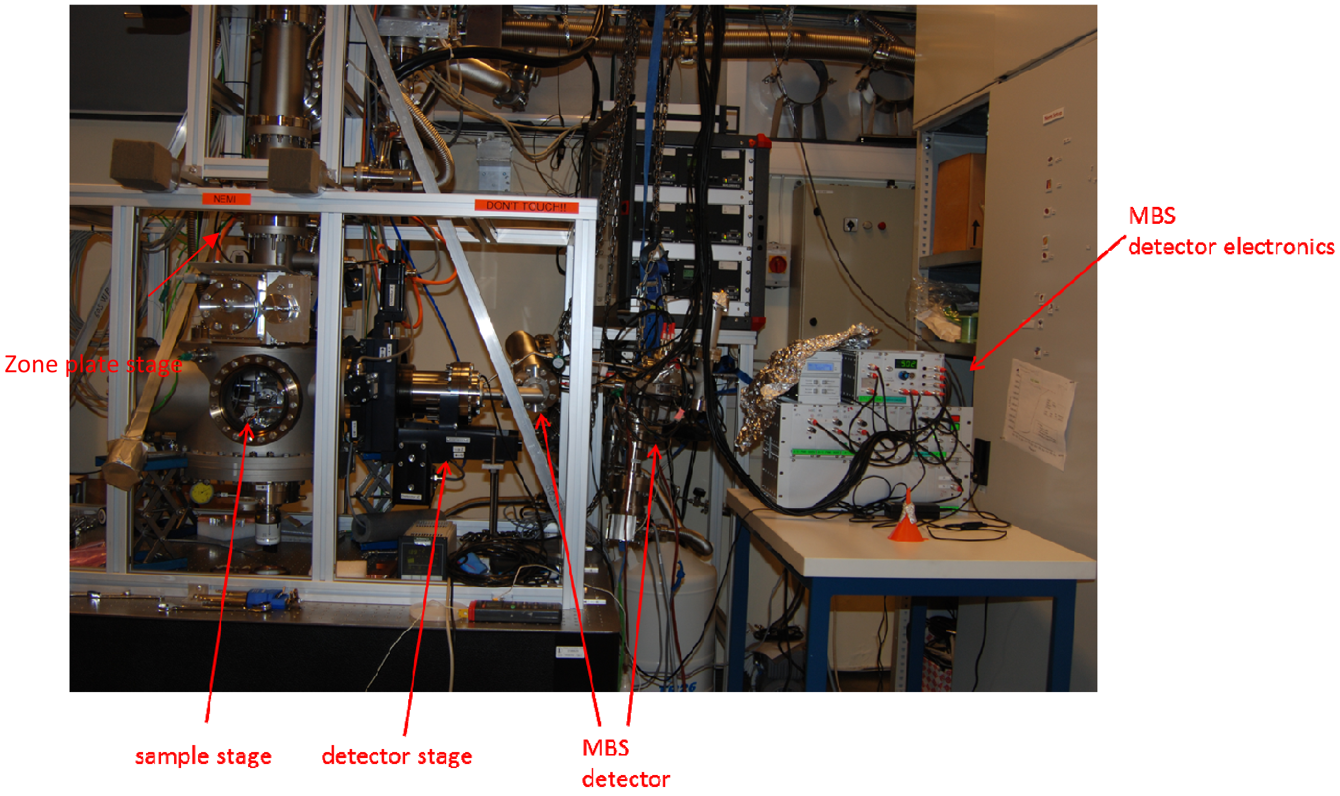


Figure 3: *Photograph of the Nemi microscope at UiB with the MB Scientific Detector attached. The beam is entering from the top and is focused with the zone plate mounted on the zone plate stage.*

The big limitation in helium microscopy up till now has been that existing helium detectors have had a much too low detection rate (detecting at the best only a few out of 1.000.000 atoms). A major sub-aim of the project as an absolutely crucial requirement for a NEMI microscope was therefore to develop a better helium detector. Because this was deemed such high risk two partners: University of Cambridge (CAM) and SME partner MB-Scientific Instruments (MB) were working on this following different methods. Status at the end of the project is that both partners managed to make detectors with an efficiency of the order of 0.01 - four orders of magnitude better than existing state of the art detectors. MBs detector has the advantage of being particularly small and relatively cheap to make. A patent application for this new detector was submitted with MB as sole inventor in the first project period and after some modifications of claims etc. it now stands shortly before approval.

During the last period of the project it was discovered that the helium flow through the micro skimmers was significantly smaller than initially predicted. This was discovered relatively late in the project, because for a long time there was a broken skimmer in the source, which lead to a larger flow. A further delay was caused by the NEMI translation stage being lost in the post. A considerable amount of effort at UiB was dedicated to solving this problem during the last project period, including a careful consideration of weather the pinhole microscope might yield a better resolution and higher intensity in the beam of the sample. A full understanding of the problem has now been obtained, supported by measurements and a method has beeen developed, which for a given desired resolution provides the optimum microscope design both for a pinhole and a focusing microscopes. The conclusion is that for high resolution microscopy, with a resolution power of better than around 500 nm it is better to use a focussing element than a pinhole setup. A patent application has been prepared by UiB during this final project period and it has now been submitted to the UK patent office. Several papers are either in preparation or accepted for publication (see template A1).

A further dedicated aim of the NEMI project was to investigate and fabricate focussing elements. A first focussing mirror for helium atoms using graphene/Ru on laser polished fused silica parabolic lenses has been developed by University Autonoma de Madrid - a major challenge proved to be getting a graphene coating that did not fracture into microcrystals. In addition UAM tested the idea of freely bending an ultrathin metal crystal coated with graphene, the idea being that the quality of the graphene layer would be better. This work has already resulted in several publications (see template A1) but a setup that can give nm focussing was not achieved within the project. As an alternative approach partner UiB fabricated and tested the first "atom sieve" (see figure 4)- a focussing elements based on a structure of holes instead of rings. With this structure it should be possible to overcome fabrication challenges and make a neutral helium microscope with a resolution of 10 nm or even less. SME partner MB scientific is planning to start a production of neutral helium microscopes based on this idea.

A further aim of NEMI was to provide nano-scale characterisation aid for two SME companies in order to help them to improve their products. Due to the various challenges with the NEMI instrument development, it was not possible to do this using the NEMI microscopy as originally planned. Fortunately metrology partner DFM managed to provide much useful information using other techniques such as AFM, scatterometry and Confocal Microscopy. DFM submitted a patent application on a novel scatterometry technique during the first project period, which is still being processed. DFM also assisted KTH in the development of the self calibration algorithm, where, originally, it was planned to use NEMI images. Instead KTH completed the work using their own white light interferometry images together with AFM and Confocal Microscopy images provided by DFM . KW can now produce 50% more samples before the mould needs to be changed and NILT is launching a new antireflection product.

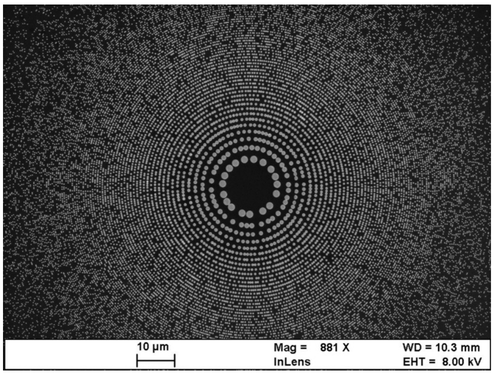


Figure 4. 2015 Raith image award winner, see template A1 for publication

Description of the Main S&T Results/Foregrounds (not exceeding 25 pages)

This section will be organised as follows: First a brief overview of the main objectives and project achievements for the final project period, followed by a detailed description of work related to all the project deliverables and milestones organised after WP. An even moree detailed description of all scientific work done in the project can be found in the deliverable reports and the publications listed in template A1.

The final main objectives according to the 4 milestones for this final period were:

1. A running NEMI instrument with sub 100 nm resolution (MS5 and MS7)
2. NEMI and AFM images of samples from partner NILT and KW with sub 100 nm resolution (MS9)
3. Self calibration algorithm with sub.100 nm scale implemented on NEMI (MS11)

Which are the main project achievements for the reporting period (last 18 months)?

1. (Corresponding to point 1 above): A running NEMI instrument with micron resolution in transmission and 10 micron resolution in transmission has been completed. A new sample chamber and pickup stage for the detector that will enable sub micron resolution was constructed by UiB and MB scientific during the final stage of the project, but due to delays in component delivery it was only installed after the end of the NEMI project. The problem with the original setup was that it was designed assuming a much higher helium flow rate than we actually have (see point 4) and so the collection angle for the reflected helium was too small, Work is ongoing.
2. (Corresponding to point 2 above): Micron scale neutral helium microscopy images of samples from partner NILT were obtained using a neutral helium pin hole microscope which has been developed in parallel to NEMI by CAM. The pin hole microscope benefits from the detector technology developed by CAM for the NEMI project. These images are the first images ever taken of a polymer sample, demonstrating how versatile the NEMI technique is. Partner DFM has supplemented with AFM images. A joint publication is in preparation.
3. The self calibration algorithm has been completed by partner KTH. It could not be tested on Nemi within the project, but it is a universal method which can be used in many contexts and considerable interest has been shown by industry (see section 3).
4. The big, fundamental problem that occurred in the NEMI project was that we had made an error estimating helium flow through micro skimmers. A broken skimmer in the source, which lead to a larger flow meant that this was not discovered initially. A further delay was caused by the NEMI translation stage being lost in the post. A considerable amount of effort at UiB has been dedicated to solving this problem during this project period. We now have a full understanding of the problem supported by measurements and have developed a method, which for a given desired resolution provides the optimum microscope design both for a pinhole and a zoneplate based microscopes. A patent application has been submitted by UiB ,two papers on the subject have been accepted for

publication in Phys Rev A. Two more papers related to the flow and speed distribution in microskimmers are in progress. We needed to develop a new method also for analysing the speed distribution. A further paper on this was published earlier this year in Rev. Sci. Inst.

5. The main result is that a 10 nm resolution zone plate microscope and a 40 nm pinhole microscope are possible with present day technology.
6. NILT has developed a very promising anti-reflection coating/surface modification which has been tested by partner DFM (see section 3)
7. MB has improved its helium detector even further, so that the detection efficiency is now close to 0.1!! This is an improvement of 4-5 orders of magnitude compared to all commercial detectors.

WP2: Helium Atom Detection.

This WP has two deliverables:

D2.1 (CAM) Cam Detector – Month 18: Fulfilled

D2.2 (MB) Two photon detector – Month 27: Fulfilled

This deliverable leads to MS1 (WP2) – Month 14: Decision on Laser Type - Fulfilled

This is a milestone related to the helium detector developed by SME partner MB. Very early in the project, MB decided to change their detector approach and not use a laser, because they got an idea how it could be done in a simpler, much cheaper way, using electron bombarding, and exploiting a combination of small volume accumulation and a background suppressing channel array, se description below. So the decision on laser type was: No laser at all.

WP2 - Description of Work:

Description of work leading to deliverable D2.1. (task 2.1)

Task 2.1.*Modified design of existing CAM detector so that it can be adapted to the NEMI setup. This task consists of electron optics simulations with the specific aim of reducing the size of the detector and make a design that can fit well on the Nemi instrument. The electron optics simulation is followed by the production of technical design drawings and manufacturing in-house of the necessary components. Finally a test phase with possible design modification.*

The modified CAM detector designed for *NEMI* is based on a high-efficiency electron-impact ioniser. Efficiency is achieved be virtue of a high ionisation-volume and it is based on electron confinement in a magnetic field together with control of ion-extraction using space-charge management. The extracted ions are injected into a magnetic mass-spectrometer that uses a 180° sector geometry. New ion-optics, based on standard electrostatic lens-elements, have been designed and developed to transport ions from ioniser to the sector and from the sector to the channel electron multiplier. The previous generation of detector was known to have sensitivity losses in the magnetic sector and the losses have been associated with a background signal that was mass independent. Both factors have been improved in the modified design. Specifically, astigmatic lenses have been designed to counter the inherent astigmatism of the magnetic-sector and a new ion-collector developed. Fig 5 is a cut-away drawing of the test rig, which has been developed to characterise the individual components. In addition to the mechanical parts illustrated in the figure, there has been significant development work on the electronic components. Power supplies for the ion-lenses and control over the electron emission have been improved. Both these features are now on web-based controllers allowing remote operation/maintenance. The instrument has a front-end specially modified to suit the *Nemi* in order to minimise response time and expedite image acquisition.

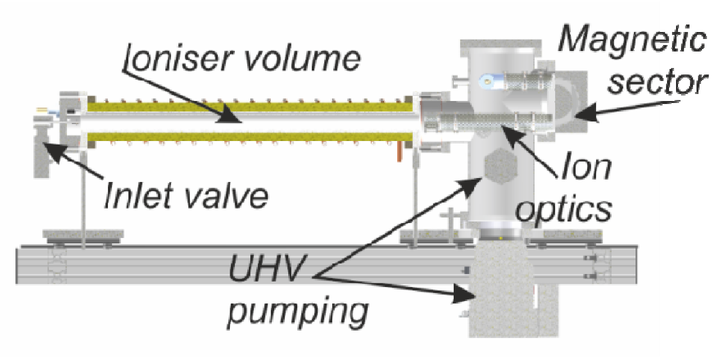


Fig. 5, Crossectional view of the main components in the CAM detector

The main contributor to the work on the design of the *Nemi* detector was Dr DJ Ward, funded as a Research Associate. He contributed to ion-optical simulations, mechanical design and was responsible for most procurement and purchasing decisions. The final instrument was completed mid 2015 and delivered to UiB in august 2016. It was designed to postpone instalment at UiB since the MB scientific detector had already been installed and there were so many unexpected issues related the the instrument performance that needed to be investigated.

<u>Description of work leading to deliverable D2.2. (task 2.2-2.4)</u>

Task 2.2 Designing and implementing test vacuum chamber for 2-photon ionisation detector including molecular beam source. This task is the first step towards deliverable D2.2. A small vacuum chamber for testing the new detector will be made including an independent detector similar to the present one at UiB for calibration.

2.3 First implementation of the new detector. This task leads to MS1 and MS2. Setting up and optimising first stage ionisation with the light source and second stage ionisation with different laser settings and cavity mirrors.

2.4 Final design, implemetation and testing of 2-photon ionisation detector to be mounted on Nemi including tuning of last parameters and adaptation of desgn to fit on Nemi instrument.

Task 2.2, design and implementing a test vacuum chamber for the detector was completed as originally planned. For task 2.3 and 2.4 the work was modified somewhat. The original approach planned was to develop a particle counting mass spectrometer with 100% efficiency in combination with a He resonance radiation source with high reflectivity refocusing mirror and a 355 nm CW. However, a very careful research by MB scientific before the project started, lead to the result that contrary to expectation it was not possible to get hold of a refocusing mirror with high enough efficiency. The idea of laser detection was therefore abandoned (the mass spectrometer was still developed) and instead an alternative electron bombardment detector with a novel back ground suppressing unit (see figure 6 top). A patent application has been submitted for the whole detector assembly with background suppressing unit. The first version of the detector (NEMI-1) with an efficiency of 10-3 is installed. The last version (NEMI-3) is ready at MB, and has an efficiency better than 10-2.

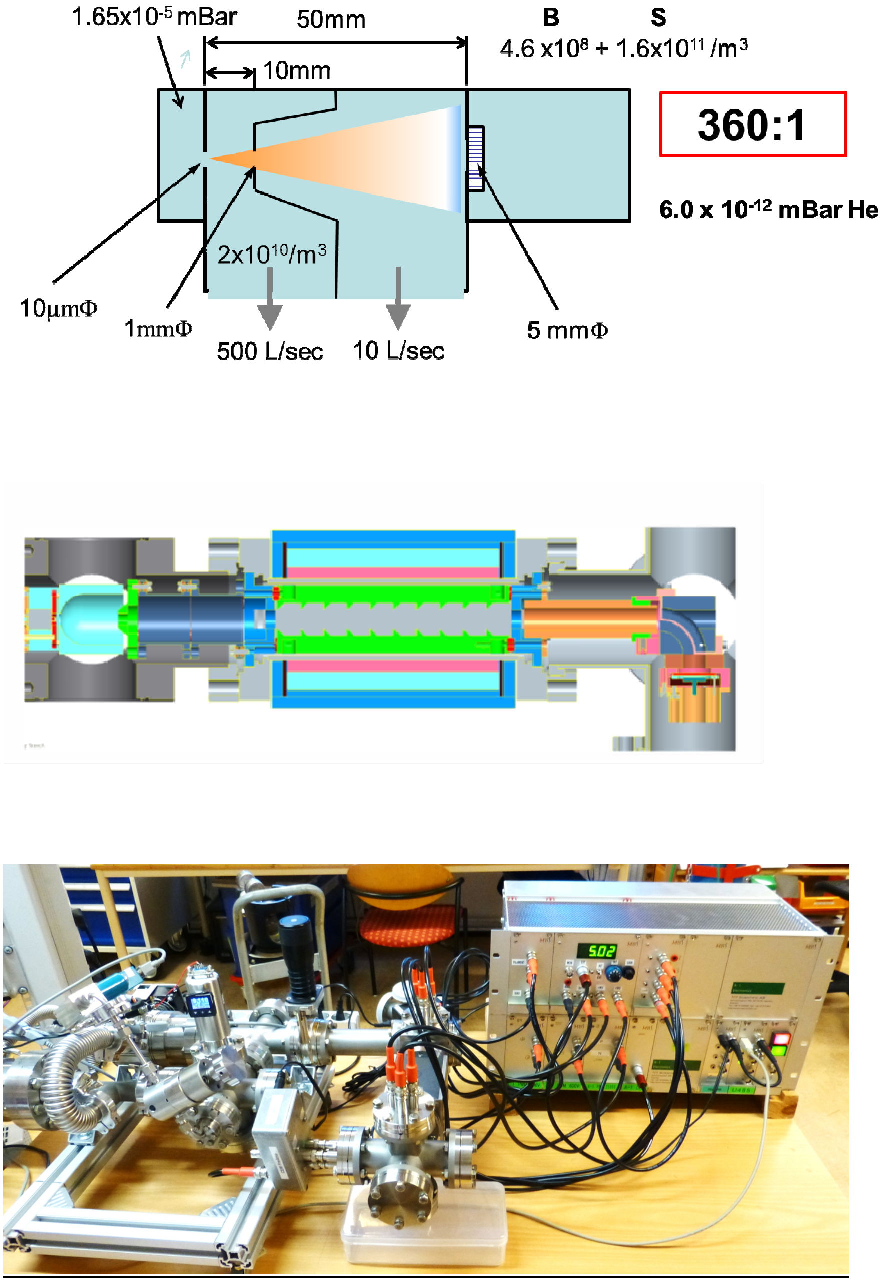


Fig.6: Top: The patented background supressing unit reducing the background from the diffuse helium signal in the sample chamber by a factor 360.. Below technical drawing and photo of the NEMI1 detector from MB. The detector can be seen mounted on the NEMI instrument in Figure 1.

WP2 Highlights

- Both detector types achieving 10-2 or better efficiency.
- Patent application on MB detector submitted

WP2 Deviations

The major deviation is partner MBs change in approach for making a detector, basing their detector on electron bombardment rather than laser ionisation. The decision has proven fruitful. The other deviation is that the instalment of partner CAMs detector was not done during the project. However, a similar detector developed in parallel by CAM for their pinhole microscope was used to obtain the images of the NILT samples, so the CAM detector development work proved very important for the project.

WP3: Helium Atom Optics

This WP has three deliverables:

D.3.1. (UiB) Velocity Selecting Zoneplates - Month 18, Partially fulfilled

D.3.2 (UAM) Parabolic graphene Mirror - Month 22, Fulfilled.

This deliverable leads to

Milestone MS3 (Mirror growth parameter, Month 12) Fulfilled and

Milestone MS4 (Sub micron focussing with graphene mirror, Month 24) Partially fulfilled

D.3.3. (UAM) Ellipsoidal graphene Mirror Partially Fulfilled.

Milestone MS5 (Sub 100 nm focussing) Not fulfilled

WP3 - Description of Work

Description of work leading to Deliverable 3.1 (Task 3.1)

Task 3.1 Designing, producing and testing velocity selecting zone plates for NEMI. It involves theoretical calculations of the desired zone plate pattern based on the geometry of the instrument and the velocity spread of the beam. Followed by the actual production of the zone plates using UiBs in-house electron beam lithography facility.

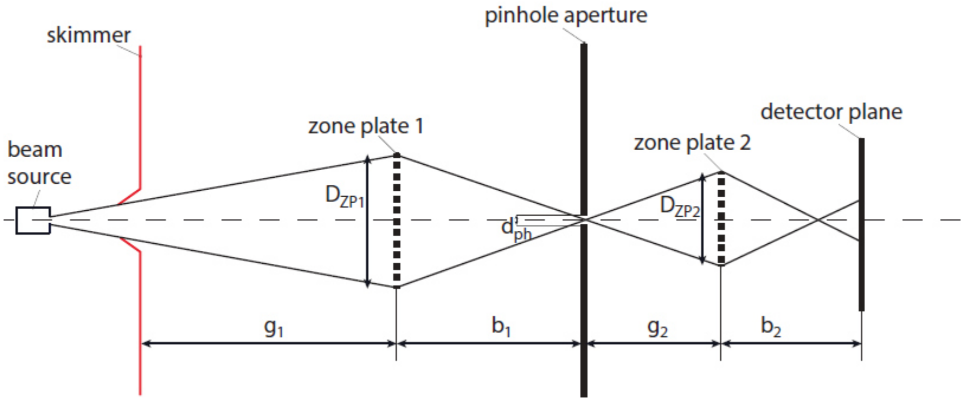


Figure 7: *Two zoneplate monochromator setup for sub 100 nm focusing.*

The original aim of deliverable 3.1 was to design the optimum parameters for a two zoneplate setup that can lead to a sub 100 nm focusing (see figure 67. On the basis of our initial calculations for the velocity spread of the zoneplates, we conclude that a sub 100 nm focusing would yield a focus with less than 0.1% of the incident beam. This theoretical work is published in Ultramicroscopy. Given the strongly reduced flow through the microskimmers, compared to what was expected, we concluded that this is too little and that for getting the sub 100 nm focussing, further there is a fundamental problem related to the fabrication of small zoneplates. The ultimate resolution of the zoneplate regardless of the velocity spread in the beam is determined by the width of the outermost zone. It is very challenging to fabricate a free standing structure less than 50 nm or so, which would then be a limit for the helium microscope resolution. It was therefore decided that a slightly different approach to what was originally decided was needed. The following was dine: Firstly using the in house nanofabrication facility, UiB fabricated and tested the first "atom sieve" (see figure 4) a focussing elements based on a structure of holes instead of rings. With this structure it should be possible to overcome fabrication challenges and make a neutral helium microscope with a resolution of 10 nm or even less, given that the velocity spread of the beam is good enough. Secondly series of intensity measurements were done at UiB using the new NEMI instrument and the existing helium scattering apparatus MAGIE. Based on these measurements full theoretical models of a zone plate microscope was done and it could be shown that 10 nm resolution is possible with a reasonable resolution using just one zoneplate. An earlier idea of combining zoneplate and collimating pinholes suggested in the midterm report could be abandoned after this full set of calculations.

<u>Description of work leading to Deliverable 3.2. and further MS3 and and MS4 (Task 3.2)</u>

Task 3.2 Producing a parabolic graphene mirror. This task leads to deliverable D3.2 and MS3 and MS4. It involves testing of different micromachined fused silica surfaces as substrates for graphene with optimal surface smoothness using helium scattering device at UAM as well as design and test of holders for curved mirrors to be used in different apparatuses (including Nemi) by partner UAM and UiB. Finally it involves optimising the growth conditions for curved mirror substrates supported by extensive SPM investigations.

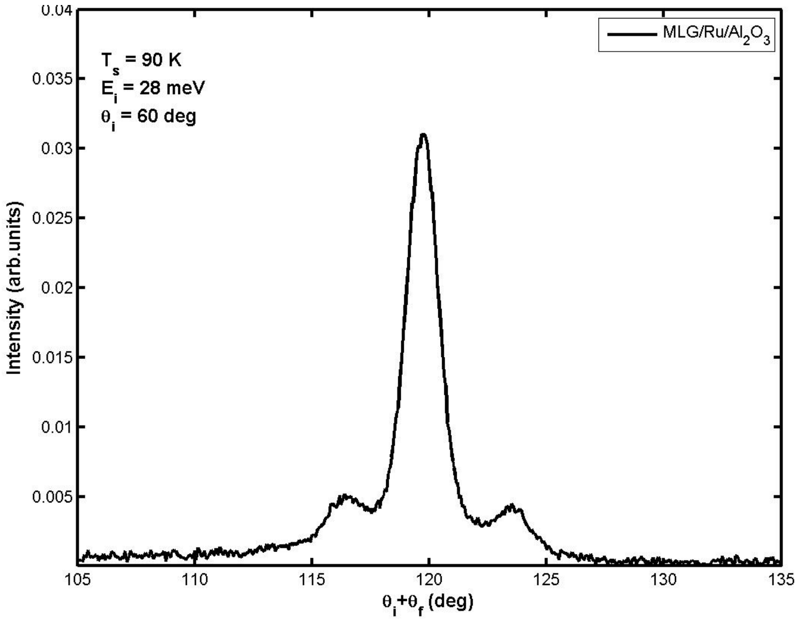


Figure 8**:** He-diffraction angular distribution from a Gr/Ru/sapphire sample prepared at UAM. Note the large specular intensity and the presence of the Moiré peaks near the specular one, which demonstrate the presence of a high-quality Gr/Ru surface

Figure 8, above. demonstrates the fulfilment of MS3: Mirror Growth Parameters determined. An excellent quality graphene surface yielding a high specular He-Intensity has successfully and reproducibly been produced.

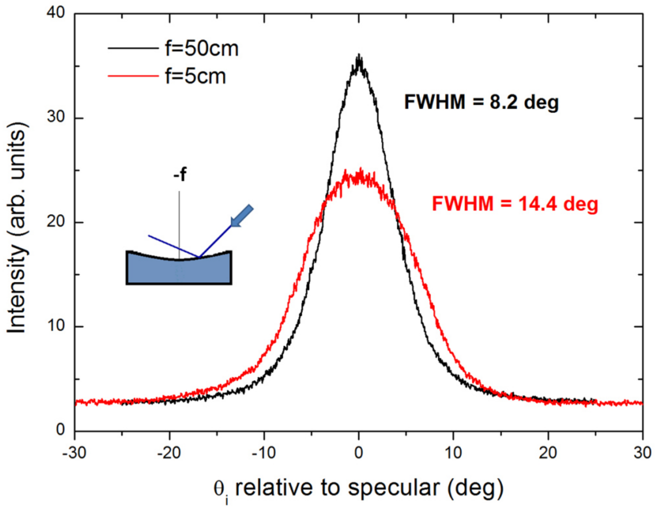


Figure 9: He-diffraction angular distributions from Gr/Ru/fused silica parabolic samples prepared at UAM. The detector is placed at 173cm from the mirror position. The full width of the specular peak is much larger for the lens with the shorter focal length (f=5cm), as expected for the case of focussing from a parabolic mirror

Figure 9 demonstrates that focussing with a parabolic mirror has been achieved and thus deliverable D 3.2. has been fulfilled and Milestone MS4 (Sub micron focussing with graphene mirror has been partially fulfilled

Description of work leading to Deliverable 3.3

Task 3.3. Producing an ellipsoidal graphene mirror. This task leads to deliverable D3.3 and milestone MS5. It involves preparing ellipsoidal mirrors in fused silica or similar coating with graphene, reoptimising the surfaces and testing the focusing at both UAM and UiB.

During the work on this deliverable it was decided that it was not actually necessary in order to achieve sub micron focussing (MS4) to make the mirror ellipsoidal, a parallel mirror would suffice. For this reason the work was focussed on creating parabolic mirrors with high quality graphene layers giving higher specular intensity. The investigation of these graphene layers lead to a total of 8 publications, including one in Nano Letters (describing an effect that was not actually advantageous from a mirror point of view). Figure 10 shows He-diffraction from graphene on a thin (200 micron) Cu(111) foil and bend in a parallel plate capacitor

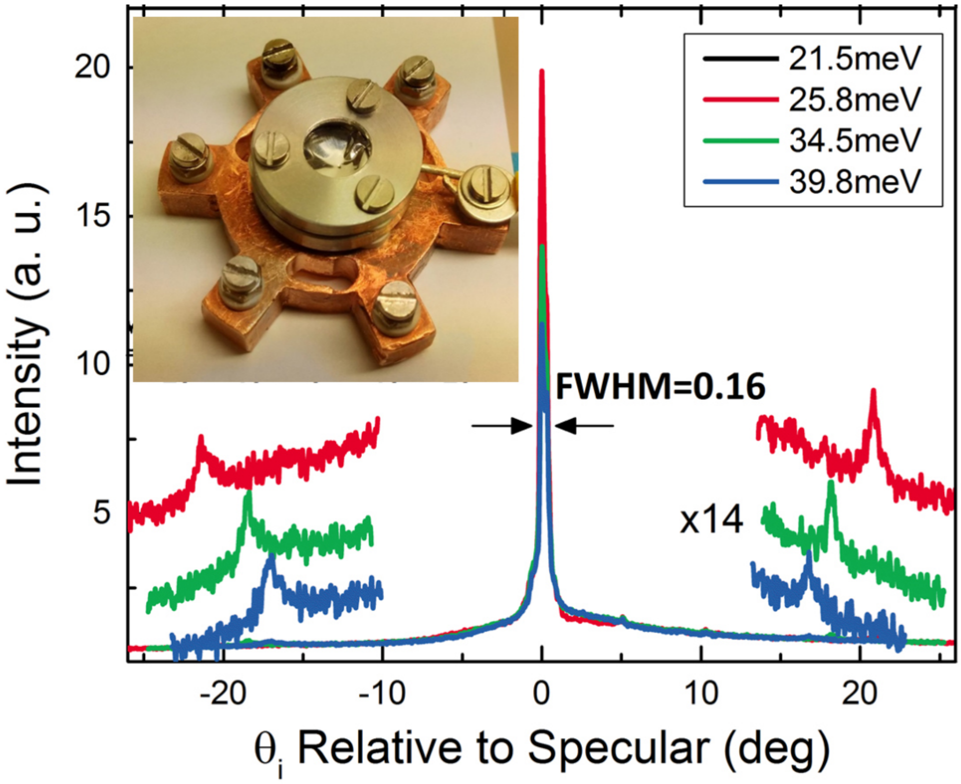


Figure 10: He-diffraction angular distribution from graphene on thin (200 μm) Cu(111) foil taken at different incident energies. The full width of the specular peak corresponds roughly to the angular resolution of the He-diffraction machine, which means that it is not limited by the sample´s quality. The inset shows the device used as a parallel plate capacitor to focus the He beam.

In summary, at the beginning of the NEMI project the He-reflectivity was around 1% and it was not possible to focus the beam. The issue of reflectivity has been successfully solved within the project. Several surfaces were which exhibit a constant reflectivity of around 20%. For comparison this is twice the intensity one can achieve with a zone plate. The remaining issue is focusing. Major advances have been made here as well: several systems capable of focussing He atoms have been identified and tested, only it was not possible to achieve the optimum focussing within the timeframe of the project. It is conclude that milestone MS4 (Sub micron focusing with graphene mirror) has been completed within 70%.

WP3 Highlights

- Focussing of He-beam from a graphene/Ru coated amorphous curved substrate - First time ever that long-range crystalline order of a coating on an amorphous, macroscopically curved substrate has been demonstrated. Paper in preparation.
- Nanoletter publication on an undesired effect: Observation of localized vibrational modes of graphene nanodomes by inelastic atom scattering", D. Maccariello, A. Al Taleb, F. Calleja, A.L. Vázquez de Parga, P. Perna, J. Camarero, E. Gnecco, D. Farías, and R. Miranda. **Nano Letters 16, 2 (2016).**
- Increase in reflectivity of the mirror surface from 1% to 20%

WP3 Deviations

- D3.1. The two zoneplate setup has been abandoned for a single atom sieve
- Sub micron focussing could not be achieved.

WP4: Integration of detector, optics and gum software in new microscope

This WP has two deliverables leading to two milestones.

Deliverable 4.1. A nemi microscope with sub micron resolution (Month 21): Partially Fulfilled. Expected Month 28

This lead to milestone MS6: A running nemi instrument with sub micron resolution and gum calibration (Month 24). Partially fulfilled

Deliverable 4.2. A nemi microscopy with sub 100 nm resolution (Month 30). Not Fulfilled

This lead to milestone MS7: A Nemi instrument with sub 100 nm resolution. Not Fulfilled

WP4 - Description of Work

Description of Work leading to Deliverable 4.1, Task 4.1

Task 4.1 Implementing the NEMI B instrument version (sub-micron focusing). This task leads to deliverable D4.1.and milestone MS6. It involves installing gum calibration software, installing motorised translation stage for detector and changing NEMI design for second, velocity selecting zone plate and designing this zone plate and installing Cambridge detector.

The implementation of the NEMI instrument was delayed effectively by a year, due to loss of the original stages in the post and then later in the delivery of the second set of stages, which were delivered three months late (in November 2014 instead of August 2014). Additional tests after delivery were needed so that they could only be installed in the NEMI instrument in January 2015. This left us time only to obtain the very first images, which were done in transmission mode using a simple accumulation detector. The resolution was about 3 micron (see Figure 2). The resolution is determined by the source size and we used a slightly bigger source (skimmer) for the first experiments, 10 micron diameter, because it made alignment easier. The focusing using the zone plates worked very well, and also the 0-stop filter, which was implemented here for the first time, worked perfectly (see Figure 11). The midterm report briefly mentions that a cooperation has been instigated with the group running the international McTrace/McScat simulation tool for modelling neutron and x-ray scattering instrumentation. The tool is used in a large range of Neutron and Syncrotron facilities. This cooperation was very sucessful. It was possible to model the results very well and explained a seemingly insensitivity in the zoneplates to the velocity distributions. Unfortunately for very small foci such as we ultimately want, this no longer holds. The work has been accepted for publication in Phys Rev A.

During the last period of the project it was discovered that the helium flow through the micro skimmers was significantly smaller than initially predicted and that this was NOT due to a problem with the skimmer pulling as initially suspected. This was discovered relatively late in the project, because for a long time there was a broken skimmer in the source, which lead to a larger flow. A considerable amount of effort at UiB was dedicated to solving this problem during the last project period, including a careful consideration of weather the pinhole microscope might yield a better resolution and higher intensity in the beam of the sample. A full understanding of the problem has now been obtained, supported by measurements and a method has been developed, which for a given desired resolution provides the optimum microscope design both for a pinhole and a focusing microscopes. The conclusion is that for high resolution microscopy, with a resolution power of better than around 500 nm it is better to use a focussing element than a pinhole setup. A patent application has been prepared by UiB during this final project period and it has now been submitted to the UK patent office. Two papers on these models have been accepted for publication in Phys Rev A and two further papers related to the flow and speed distribution in microskimmers are in progress. In order to do the work it was necessary to develop a new method for analysing the speed distribution. A further paper on this was published earlier this year in Rev. of Sci. Inst.

Based on our calculations it was clear that the current design for NEMI was not very favorable. The best result achieved with the original setup using a detector from MB was around 10 micron resolution and quite a low intensity (see Figure 12). Luckily CAM had developed a helium pinhole microscope in parallel using detector technology developed in the NEMI project. Using this instrument it was possible to make the first neutral helium microscopy images of a polymer sample (provided by partner NILT). These images are micron scale .

On the basis of the results from CAM and UiB we conclude that Milestone MS6 is partly fulfilled.

A new sample chamber and pickup stage for the detector that will enable sub micron resolution was constructed by UiB and MB scientific during the final stage of the project, but due to delays in component delivery it was only installed after the end of the NEMI project.

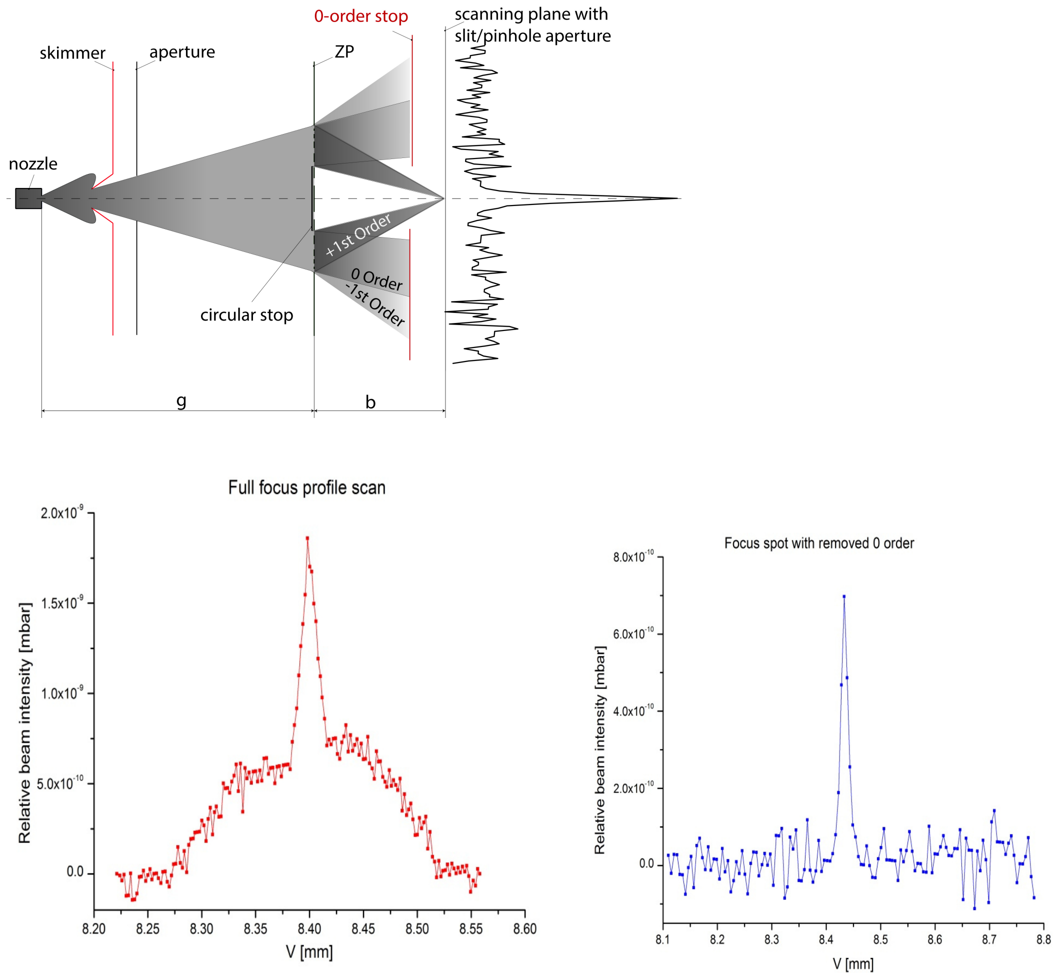


Figure 11: Top, illustration of the 0-order filtering principle. Below, the focused atom beam without 0-order stop, to the left - the 0-order background is clearly visible and with 0-order stop to the right. The background is gone.

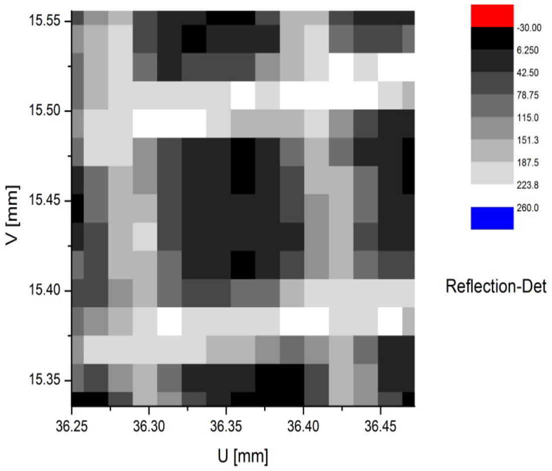


Figure 12. Reflection image from the UiB NEMI focused beam instrument using a TEM grid as sample

Deliverable 4.2. A nemi microscopy with sub 100 nm resolution (Month 30) and milestone MS7

Due to the problem with the flow through the microskimmers described above this deliverable could not be fulfilled within the project period, however it was possible to show on the basis of measurements and modeling that it is possible.

WP4 Highlights

- NEMI microscopy images in reflection obtained with micron scale resolution
- First NEMI microscopy images ever of a polymer sample
- First demonstration ever of successful 0-order filtering (order sorting aperture) in helium atom focusing with a Zoneplate.
- Full theoretical understanding of zoneplate and pinhole microscope now developed and patented.

WP4 Derivations

The major derivation was first the one year delay in implementing NEMI due to the loss of the original translation stages February 2014, new translation stages installed January 2015. The second most serious deviation was caused by the unexpected low flow through the microskimmers.

WP5: Pilote Studies on Forming and Forging tools with Nanostructured coatings

This Workpackage has 5 deliverable

D5.1. NEMI and AFM images of nanostructured coatings with micron scale resolution (Month 18): Partially Fulfilled

D5.2. NEMI and AFM images of optimised nanostructured coatings with sub micron resolution (Month 24): Partially Fulfilled

Related to Milestone MS8: NEMI and AFM images from Partner NILT and KW with sub-micron (Month 24) resolution. Partially Fulfilled

D5.3. NEMI and AFM images of reoptimised nanostructured coatings (Month 39) Partially Fulfilled

D5.4. Improved surface coatings (Month 30) Fulfilled

D5.5. Reoptimised surface coatings. (Month 39) Fulfilled

WP 5 - Description of Work

Description of Work leading to Deliverable D5.1 and D5.2, D5.3 and D5.4. Task 5.1, 5.2 and 5.3

Task 5.1 First images of nanostructured coatings using Nemi A (micron scale resolution). This task leads to deliverables D5.1. It involves preparing flat test surfaces, coated and non-coated. At least 10 surfaces of different types will be produced to test for reproducibility. Surfaces will be left under *"typical" conditions for "typical" periods of times followed by a testing of test samples with optical methods, AFM and Nemi A. Special properties: Material characterisation, roughness on nano- and micrometer scale and wera of the coatings. Material characterisation will be done using spectroscopic reflectometry and generalised ellipsometry. Element analysis of the coating are obtained using EDX. Roughness on nano and micrometer scale will be done using AFM and confocal white light inferometer (WLI).*

5.2 Images of optimised coatings using NEMI B (sub micron resolution). This task leads to deliverables D5.2 and MS8. Preparing samples with typical shapes (in particular also high aspect ratios) using typical coatings- again at least 10 surfaces of different types will be produced to test for reproducibility. Testing typical samples with WLI, reflectometry, AFM and NEMI.

5.3 Improved surface coatings. This task leads to deliverable 5.4. Optimisation of nanostructured form and forging coatings on the basis of information obtained.

5.4 Testing and preparing samples in an optimisation and reoptimisation step (Nemi C). This task leads to deliverables D 5.3, D 5.5 and Milestone MS9. It involves testing the samples in a similar manner as described above, but using the highest resolution NEMI instrumnent

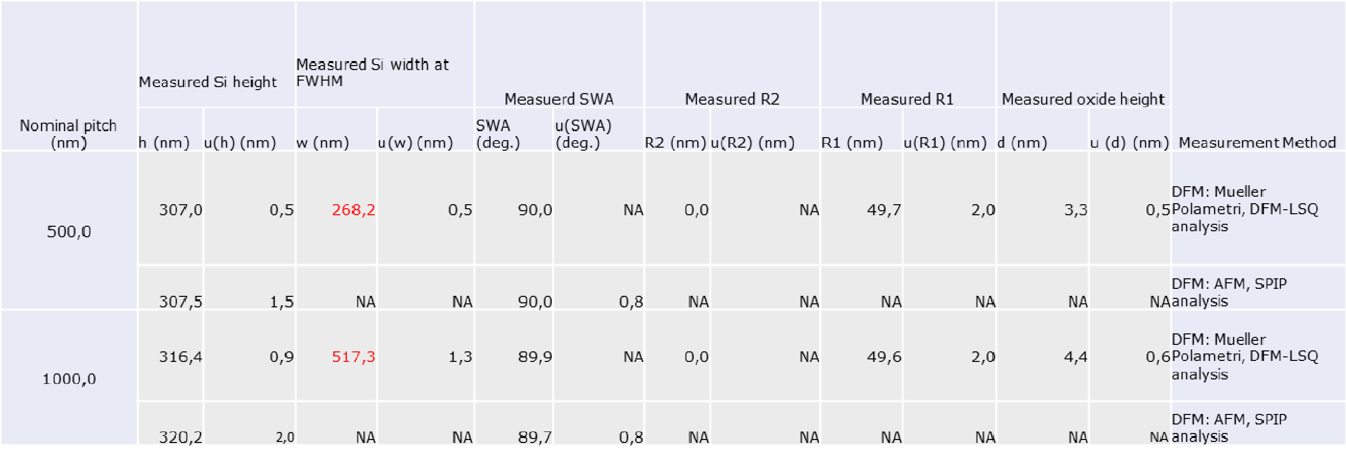
Dozens of nanostructured coatings from NILT and KW were analysed. In addition to AFM the samples have also been analysed by DFM using Mueller Polarimetry. It was decided to extend the analysis because the images from NEMI were not available (see WP4 description).

DFMs Mueller Polarimetry setup and analysing software was used to measure samples showing that Mueller Polarimetry is capable of reconstruction the topography of these samples with extremely high accuracy that are beyond state of art. In addition to the topography parameters (height, width and sidewall angle) we were able to measure a nanometer thick SiO2 coating layer on top of the sample. The metrological characterization of all the hardware components in the home build the Mueller Polarimetry setup and the full metrological analysing software with uncertainty propagation are of uttermost importance in achieving this high accuracy.

The main result for NILT was that the anti-sticking coating was in fact good enough and that a repeated use did not lead to any wear and importantly did not lead to any transfer of coating from stamp to substrate in the imprint process. This is particularly important for biological applications. For KW on the other hand the investigations done by DFM lead to substantial improvement so that twice as many items can now be produced before the injection molding tool need to be exchanged. Especially the investigation of roughness and material composition on very steep sidewall was crucial.

Description of Work leading to Deliverable D5.5.

Because the work on the anti-sticking coatings could essentially be finished ahead of time and because it fitted the development of the company NILT decided in the last part of the project to focus on the development of nanostructures with anti-reflective functionality when replicated in polymers. For many applications, reducing the reflection and improving the transmission or absorption of light from wide angles of incidence in a broad wavelength range are crucial for enhancing the performance of solar cells, photodetectors, light-emitting diodes (LED) and flat panel displays. For many of these applications it would be highly desirable if anti-reflective nanostructures could be produced at an industrial scale at a very low cost. DFM performed AFM and optical transmission experiments on a range of NILT samples. With this information NILT could successfully develop a new antireflective structuring (see Figure 15). NILT have recently experienced a technological breakthrough as they have developed a method that allow for nanostructuration of a bulk steel injection moulding tool insert with structures with lateral dimensions below 100 nm. NILT has also demonstrated replication of the structures by injection moulding used for mass production of polymeric parts. This breakthrough in combination with the promising results from the nanostructured anti-reflective surfaces developed in the NEMI project opens up new market opportunities for NILT. NILT are already in dialogue with the first customer for this technology. The method for nanostructuration of a metal insert has already been patented by the Technical University of Denmark, with NILT as co-authors.



Nominal pitch (nm)	Measured Si height		Measured Si width at FWHM		Measuerd SWA		Measured R2		Measured R1		Measured oxide height		
	h (nm)	u(h) (nm)	w (nm)	u(w) (nm)	SWA (deg.)	u(SWA) (deg.)	R2 (nm)	u(R2) (nm)	R1 (nm)	u(R1) (nm)	d (nm)	u (d) (nm)	Measurement Method
500,0	307,0	0,5	268,2	0,5	90,0	NA	0,0	NA	49,7	2,0	3,3	0,5	DFM: Mueller Polametri, DFM-LSQ analysis
	307,5	1,5	NA	NA	90,0	0,8	NA	NA	NA	NA	NA	NA	DFM: AFM, SPIP analysis
1000,0	316,4	0,9	517,3	1,3	89,9	NA	0,0	NA	49,6	2,0	4,4	0,6	DFM: Mueller Polametri, DFM-LSQ analysis
	320,2	2,0	NA	NA	89,7	0,8	NA	NA	NA	NA	NA	NA	DFM: AFM, SPIP analysis

Table 1 Muller Polarimetry and AFM measurements showing that it is possible to determine the geometrical parameters of a grating with extreme high accuracy. The Muller Polarimeter was also able to measure the oxide height (thickness) that was formed on top of the structure. The designation used in the table is explained in figure 1. The uncertainty of a measurand is given by u(measurand).

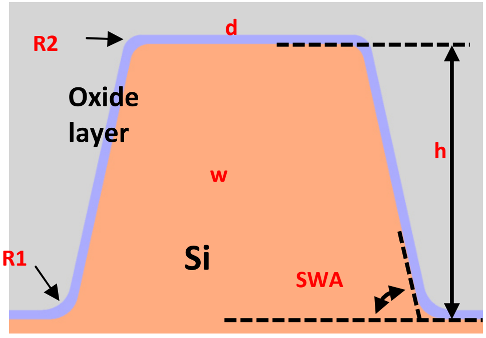
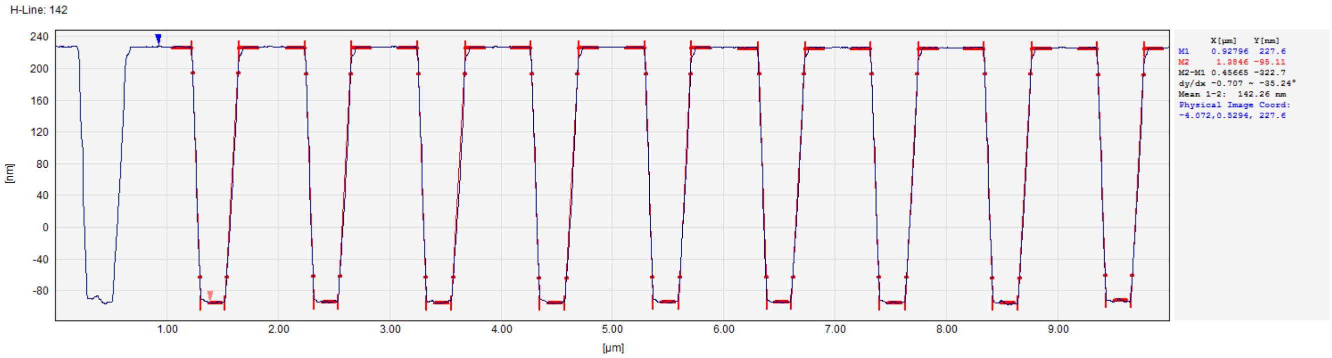


Figure 13. Explanation of the designation used in table 1.



```
        X[µm]    Y[nm]
M1      0.92796  227.6
M2       1.3846 -95.11
M2-M1 0.45665 -322.7
dy/dx -0.707 ~ -35.24°
Mean 1-2:  142.26 nm
Physical Image Coord:
-4.072,0.5294, 227.6
```

Figure 14: AFM profile of an object demonstrating how the height of a sample as the vertical distance between the red horizontal lines

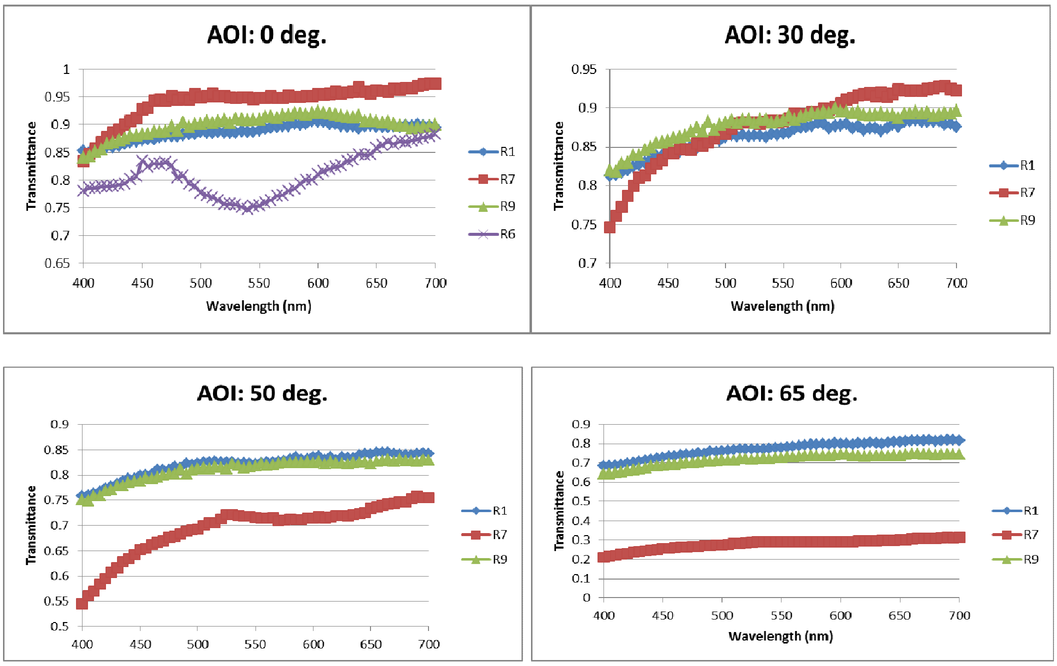


Figure 15 - Measurement of transmittance for NILT antireflective structures.

WP 5 - Highlights

- First demonstration that Muller Polarimetry (DFM home built setup) can be used to measure a nanometer thin SiO2 coating layer on top of a patterned sample.
- DFM patent submitted "Multispectral scatterometer imaging system"
- On the basis of DFM images KW has been able to improve the surface coating on their moulds so that they can now produce twice as many items before the injection molding tool needs to be exchanged
- NILT has developed a new anti-reflective surface with a wide range of application which was tested by DFM

WP 5 - Major Derivations

The major derivation is the fact that the NEMI images (micron and sub micron resolution) could not be obtained (see WP4). Fortunately very important information could be obtained by the AFM and optical characterisation performed by partner DFM so that the major goal of this WP: Improved surface coatings for the two partners NILT and KW could still be fulfilled. KW in fact obtained a significant improvement of their coating (see highlights) ahead of time. A further derivation was caused by NILT changing focus from anti-sticking coatings to antireflective structures. This lead to very successful results meaning that NILT is close to launching a new product. The NILT derivation approved in advanced by the Scientific officer and scientific expert and the project coordinator.

WP6: Pilot Studies on Standardised Test Artifacts: Self calibration Algorithm

This WP has 7 Deliverables and two Milestones

D6.1 NEMI Images (micron resolution), standard objects micron scale (Month 18) Partially Fulfilled

D6.2 NEMI B Images (sub micron resolution), standard objects (Month 24) - Not Fulfilled

D6.3. NEMI C Images (sub 100 micron resolution), standard objects (Month 39) - Not Fulfilled

D6.4 3D-self calibration (Month 22) Fulfilled

This work leads to MS10 Self-calibration algorithm with micron scale, NEMI data (Month 24)

D6.5 3D Self-calibration with simulated data (Month 30) Fulfilled

D6.6 3D Self-Calibration with NEMI data (Month 39) - Not Fulfilled

D6.7. Report on NEMI to ISO standard group (Month 42) - Partially Fulfilled

The work lead to milestone

MS10 - Self calibration algorithm with micron scale NEMI data implemented - Partially Fulfilled

MS11 - Self calibraiton algroithm with sub-100 nm scale. NEMI data implemented - Partially Fulfilled.

WP6 - Description of Work

Description of Work leading to Deliverables 6.1, 6.2 and 6.3: Task 6.1, 6.2. and 6.3

Task 6.1 Testing standardised test objects using NEMI A and standard instruments. This taks leads to delivarable D6.1. It involves selecting suitable test samples on the micron and nano-scale. Special propoerties: high aspect ratios, corner definitions, roughness on the nano and micron scale. It is importnat to include testing on the micron scale to ensure a smooth transition and comparability between the micron- and nano- scale. Design and ordering of dedicated high aspect ratio structures for devcelopment of 3D self-calibration algorithms and procedures. Testing test samples with optical tests and mechanical profilometry. To ensure clear comparisons and to illustrate the possibilities all tests will be performed with all samples, even if it is clear that not all tests can resolve all features, *the samples will also be tested. Testing the samples (as far as possible)with AFM, ellipsometry, white light interferometry and scatterometry.*

6.2 Similar tests to the ones described above, carried out using NEMI B and standard instruments. This task leads to deliverable 6.2.

6.3 Similar tests to the one described above, carried out using NEMI C and standard instruments. This task leads to deliverable D 6.3.

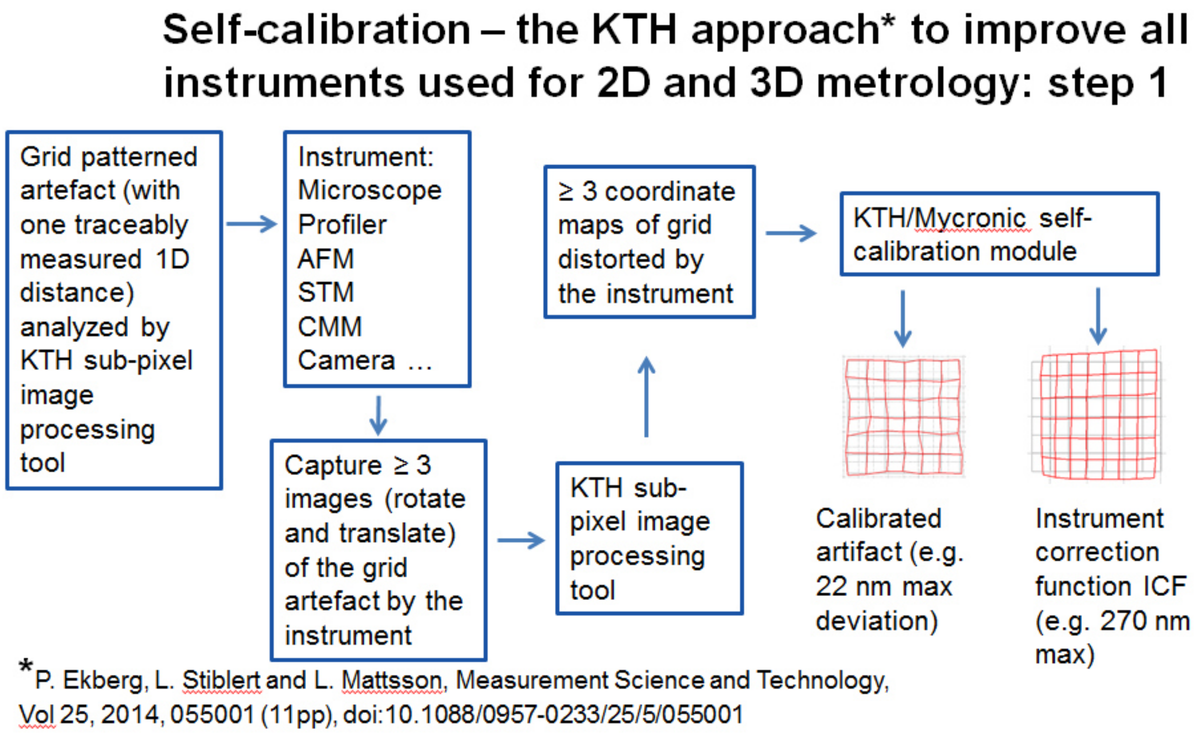
Because of lack of NEMI data (see WP4) D.6.1-6.3 could not be fulfilled. However, instead DFM and KTH carried out a range of measurements on test artefacts using AFM and optical tests (confocal microscopy and withe light interferometry) and these measurements were used as the basis for experimental tests of the self-calibration algorithms.

Description of Work leading to Deliverables 6.4, 6.5 and 6.6: Task 6.4

6.4 Development of 3D self calibration algorithms and procedures, this task leads to deliverables D6.4, D6.5 and D6.6 and involves image analysis and edge detecting algoriths for sub-pixel metrology of NEMI images and 3-D self calibration test based on NEMI measurements

Self-calibration algorithms have been developed as described and the performance has been tested by thorough modelling of the process. Subsequently new sub-pixel image analysis and algorithms have been developed and tested on images of the test artefact using confocal microscopy and white light interferometry at DFM and KTH respectively. Self-calibration of these images has revealed remarkable improvements of accuracy in microscope images, as the self-calibration process yields an instrument correction function (ICF) as well as a the accuracy of the artefact itself. Thus, the centre of gravity <(in X,Y) of the Z=80 nm high and Ø 8 um discs, distributed in a matrix pattern with 25 um pitch on the artefact, **are determined with an uncertainty of ~3 nm** in the case of the white light interferometer measurements.

This is breakthrough news, and opens up a new era for ultraprecision metrology using imaging devices. The requirement for this precision is that the instruments are stable and provide a high repeatability, which might be difficult for mechanical scanning systems. The concept of this new approach is shown in Figs 16 and 17.



Self-calibration – the KTH approach* to improve all instruments used for 2D and 3D metrology: step 1

Grid patterned artefact (with one traceably measured 1D distance) analyzed by KTH sub-pixel image processing tool

Instrument:
Microscope
Profiler
AFM
STM
CMM
Camera …

Capture ≥ 3 images (rotate and translate) of the grid artefact by the instrument

KTH sub-pixel image processing tool

≥ 3 coordinate maps of grid distorted by the instrument

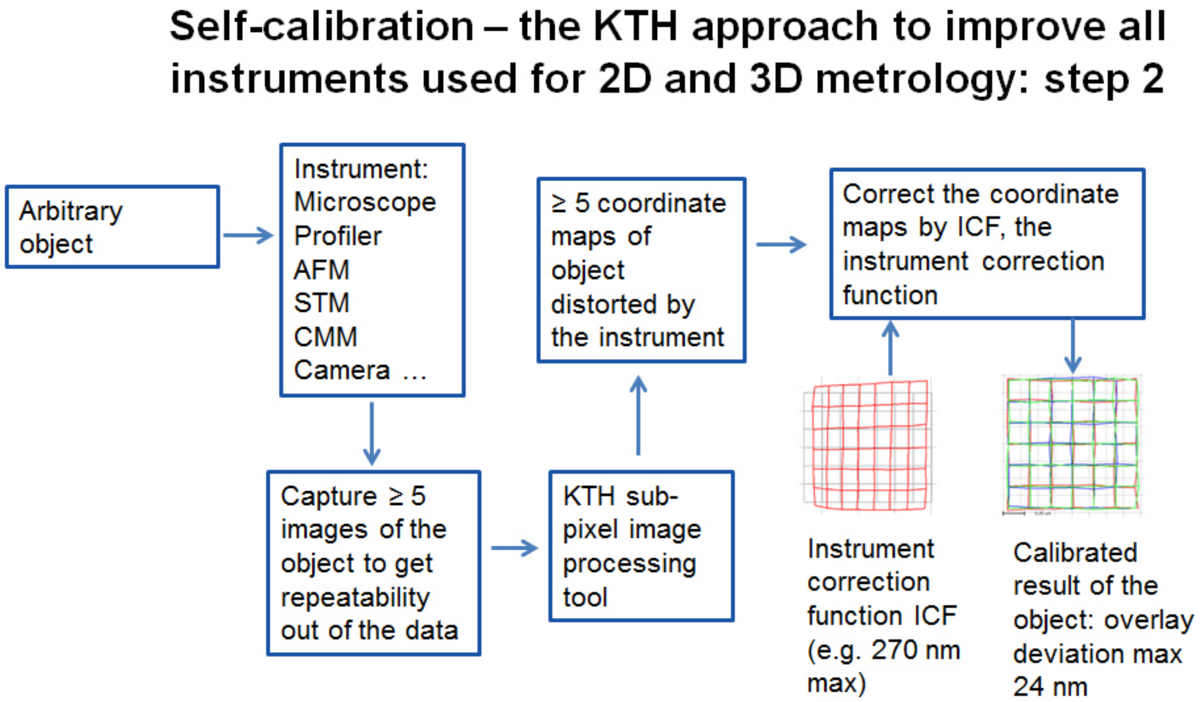
KTH/Mycronic self-calibration module

Calibrated artifact (e.g. 22 nm max deviation)

Instrument correction function ICF (e.g. 270 nm max)

*P. Ekberg, L. Stiblert and L. Mattsson, Measurement Science and Technology, Vol 25, 2014, 055001 (11pp), doi:10.1088/0957-0233/25/5/055001

Fig.16 Self-calibration yields Instrument correction function and a calibrated artefact.



Self-calibration – the KTH approach to improve all instruments used for 2D and 3D metrology: step 2

Arbitrary object

Instrument:
Microscope
Profiler
AFM
STM
CMM
Camera …

Capture ≥ 5 images of the object to get repeatability out of the data

KTH sub-pixel image processing tool

≥ 5 coordinate maps of object distorted by the instrument

Correct the coordinate maps by ICF, the instrument correction function

Instrument correction function ICF (e.g. 270 nm max)

Calibrated result of the object: overlay deviation max 24 nm

Fig.17 By eliminating the instrument distortion a much higher accuracy is obtained on arbitrary objects.

The results we have obtained on the patterned TED Pella artefact, purchased for performance testing of Nemi, shows that **the positioning of the pillars are accurate to better than ~15 nm**. The pattern used for the self-calibration is shown in Fig.18.

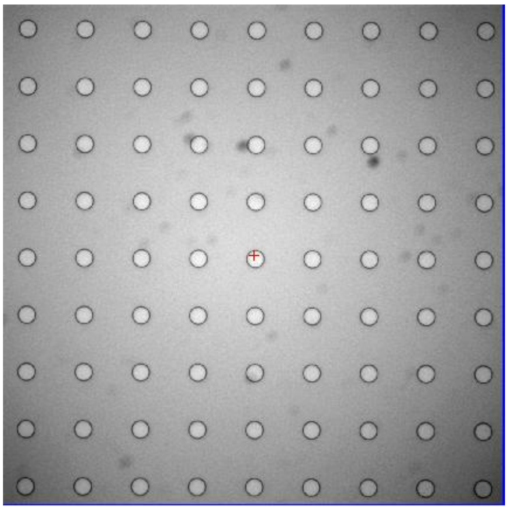


Fig.18 Microscope Image of the calibrated artefact with 80 nm high and Ø 8 um discs, distributed in a matrix pattern with 25 um pitch. Note the non-uniform illumination that has to be taken care of by the sub-pixel image processing tool when determining centre of gravity of the discs at nm-accuracy.

Three principal approaches for 3D calibration are presented in D6.4:

Concept 1 (Object slicing):

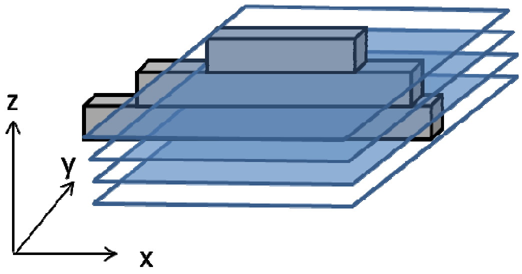


Fig. 19 The principles of object slicing. The object is measured in well-defined planes.

Concept 2 (object projection)

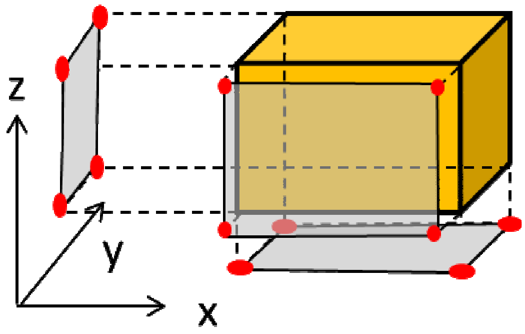


Fig. 20 Points of the object is projected on the YZ,XY and XZ plane. This require the object to be rotated around its principal axes with a high precision.

Concept 3 (real 3D self-calibration)

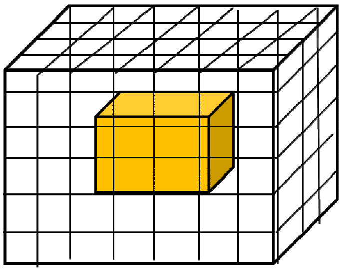
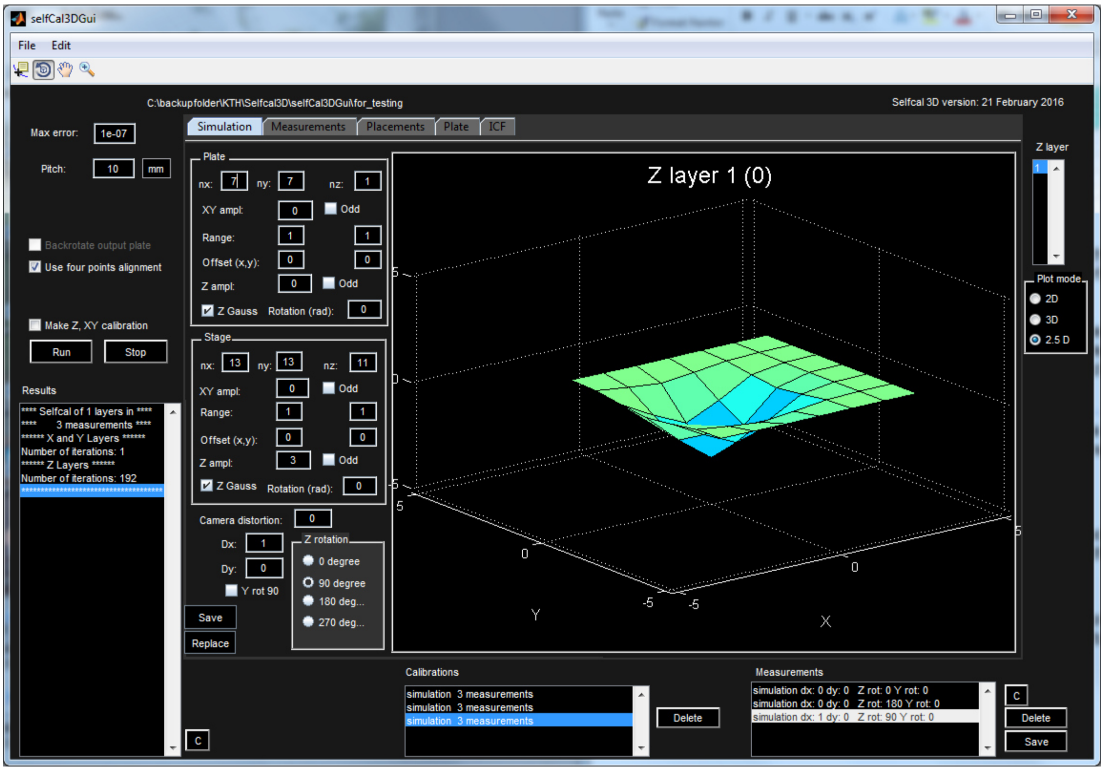


Fig 21. The object resides in a volume of voxels. Deformations of the 3D grid (voxels) in this volume represent the 3D Instrument Correction Function. The shape of the object is also defined as deviations in the 3D voxel grid.

In D6.5 the algorithms were tested with simulated data. A distinction is made between 2.5 D self calibration, which refers to an opaque surface measurements (essentially the NEMI situation) and "true" 3D self calibration where it is possible, in principle, to measure any point on the object in 3D.

Successful solutions could be found for both cases, further, to facilitate the application in many different disciplines a flexible user interface has been developed. See figure 14.



C:\backupfolder\KTH\Selfcal3D\selfCal3DGui\for_testing

Selfcal 3D version: 21 February 2016

Max error: 1e-07

Pitch: 10 mm

☐ Backrotate output plate

☑ Use four points alignment

☐ Make Z, XY calibration

Plate

nx: 7 ny: 7 nz: 1

XY ampl: 0 ☐ Odd

Range: 1 1

Offset (x,y): 0 0

Z ampl: 0 ☐ Odd

☑ Z Gauss Rotation (rad): 0

Stage

nx: 13 ny: 13 nz: 11

XY ampl: 0 ☐ Odd

Range: 1 1

Offset (x,y): 0 0

Z ampl: 3 ☐ Odd

☑ Z Gauss Rotation (rad): 0

Camera distortion: 0

Dx: 1

Dy: 0

☐ Y rot 90

Z rotation

○ 0 degree

● 90 degree

○ 180 deg...

○ 270 deg...

Plot mode

○ 2D

○ 3D

● 2.5 D

```
**** Selfcal of 1 layers in ****
****      3 measurements ****
****** X and Y Layers ******
Number of iterations: 1
****** Z Layers ******
Number of iterations: 192
************************************
```

Calibrations

simulation 3 measurements
simulation 3 measurements
simulation 3 measurements

Measurements

simulation dx: 0 dy: 0   Z rot: 0 Y rot: 0
simulation dx: 0 dy: 0   Z rot: 180 Y rot: 0
simulation dx: 1 dy: 0   Z rot: 90 Y rot: 0

Figure 22: The 3D self-calibration GUI used for handling real measurements and simulations.

The milestones MS10 and MS11 can be said to be partially fulfilled in that self algorithms have been developed and tested with experimental data obtained from white light interferometer measurements and others. They have just not been tested with Nemi data.

Description of Work leading to Deliverables 6.7, task 6.5

6.5 Report and feed back discussion with the ISO-TC213/Working Group 16. This task leads to deliverable D6.7

This deliverable reports the KTH activity performed in collaboration with the Swedish standardization body, SIS and discussions with the convener of the ISO/TC 213/WG 16 Areal and profile surface texture. It was intended to be a summary report proposing NEMI to be a standardised metrology tool for surfaces, but technical problems with the NEMI instrument prevented that.

The work carried out involves a presentation of a tentative layout of a NEMI standard, by interacting with the Swedish standards committees SIS/TK 507/AG 6 Mätteknik GPS och Ytstruktur (Metrology Geometrical Product Specification and Surface structure) and SIS/TK 507/AG 5 – Toleranser (Tolerances).

The second part of this delivery brings up the unique self-calibration results we have achieved on images obtained from 3D optical profilers and an Atomic Force Microscope. These results have received a lot of attention by the SIS tolerance group, and connections will be established with the ISO/TC 213/WG 10 – Coordinate measuring machines committee in the future. A spin-off service for self-calibration is already in action thanks to a KTH Innovation initiative.

The new 3D self-calibration algorithm based on simulated data will probably be experimentally tested in a joint collaboration with a British University, to prove that the principles of the actual method we selected will work as intended. If it works just as fine as the 2D self-calibration it will open up a completely new possibility to perform a standardised self-calibration on 3D coordinate measurement machines at considerably reduced cost and off-line service time.

WP6 Highlights

- 3D and 2.5 D self-calibration have successfully been performed with an uncertainty of approx. 3nm. Almost two orders of magnitude better than what was envisaged at project start.

WP6 Major Deviations

The major deviation in WP6 is that the work had to be carried out without the use of NEMI data. However, by making use of replacement images obtained by white light interferometry and confocal microscopes on the artefact to be used in Nemi it was possible to experimentally verify the WP6 developed self-calibration software. The result achieved are far beyond our initial ultimate goals (sub

100 nm resolution)., and we have proven a state of the art the calibration uncertainty of the artefact and the microscopes to be ~3 nm (1σ). The algorithms are now ready for use in the Nemi images, and the lack of these images has not hampered the work on developing the self-calibration algorithms.

Use and dissemination of foreground

This section present firstly a list of all scientific peer reviewed publications that have come out of this project (template A1). This is followed by a list of dissemination activities that has taken place during the project (template A2). This is followed by a list of patents in template B1 and a list of foreground in template B2. The list of foregrounds is followed by a detailed description of how it is planned to exploit each of the individual foregrounds that has been established and developed during the project in the future.

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication ?
1	*Theoretical model of the helium zone plate microscope*	*B. Holst*	*Physical Review A*	*Accepted*	*AIP*	-	*2016/2017*			no
2	Theoretical model of the helium pinhole microscope	B. Holst	Physical Review A	Accepted	AIP		2016/2017			no
3	Zero order filter for diffractive focusing of de Broglie matter waves	B. Holst	Physical Review A	Submitted	AIP		2016/2017			no
4	A modified time of flight method for precise determination of high speed ratios in molecular beams	B. Holst	Review of Scientific Instruments	87	AIP		2016	023102	http://scitation.aip.org /content/aip/ journal/rsi /87/2/10.1063/1.4941336	No no
5	Focusing of a neutral helium beam with a photon.sieve structure	B.Holst	Physical Review A	91	AIP		2015	043608	http://journals.aps.org/pr a /abstract /10.1103 / PhysRevA.91.043608	no
6	Optimization of a constrained linear monochromator design for neutral atom beams	T. Kaltenbacher	Ultramicroscopy	163	Elsevier		2016	62-68	http://www.sciencedirect. com/science/article/pii/S 0304399116300109	no
7	Low-energy excitations of graphene on Ru(0001)	D. Farias	Carbon	93	Elsevier		2015	1-10	http://www.sciencedirect. com /science/article/pii /S000862231500425X	no
8	Observation of localized vibrational modes of graphene nanodomes by inelastic atom scattering	D. Farias	Nano Letters	16	ACS		2016	2-7	http://pubs.acs.org/doi/a bs /10.1021 /acs.nanolett. 5b02887	no
9	Acoustic surface phonons of graphene on Ni(111)	D. Farias	Carbon	99	Elsevier		2016	416-422	http://www.sciencedirect. com/ science/article /pii /S0008622315305236	no

10	Unveiling the Mechanisms Leading to H2 Production Promoted by Water Decomposition on Epitaxial Graphene at Room Temperature	D. Farias	ACS Nano	10	ACS		2016	4543-4549	http://pubs.acs.org/doi/abs /10.1021 /acsnano.6b00554	no
11	Helium diffraction and acoustic phonons of graphene grown on copper foil	D. Farias	Carbon	95	Elsevier		2015	731-737	http://www.sciencedirect.com /science/article/pii /S0008622315302128	no
12	Quality of graphene on sapphire: long-range order from helium diffraction versus lattice defects from Raman spectroscopy	D. Farias	RSC Advances	6	RSC		2016	2135-21245	http://pubs.rsc.org/en/content /articlelanding /2016/ra/ c5ra27452d#!divAbstract	yes
13	Phonon dynamics of graphene on metals	D. Farias	Journal of Physics: condensed matter	28	IOP		2016	103005	http://iopscience.iop.org/article /10.1088/0953-8984/28/10/103005/meta	yes
14	A new 2D-self-calibration method with large freedom and high-precision performance for imaging metrology devices	L. Mattson	Proceedings of the 15th International Conference of the European Society for Precision Engineerng and Nanotechnology		EUSPEN		2015	159-160		
15	Imaging scatterometry for flexible measurements of	P. E. Hansen	Optics Express	24	OSA		2016		DOI:10.1364/OE.24.001109	yes

	patterned areas									
16	Traceable Mueller polarimetry and scatterometry for shape reconstructionof grating structures	P. E. Hansen	Applied Surface Science	Submitted	Elsevier					
17	Multiphonon Excitation and Quantum Decoherence in Neon Scattering from Solid Surfaces	D. Farias	(Phys Rev B)	Submitted						
18	Helium Microscopy Images of a Polymer Structure (working title)	All partners		In preparations, measurements finished						
19	Helium Microscopy Images using a focused helium beam (working title)	All partners		In preparations, measurements not finished						
20	3D self calibration applied to neutral helium microscopy (working title)	All partners		In preparation, measurements finished						
21	He-diffraction from a curved graphene layer grown on an amorphous substrate	D. Farias		In preparation, measurements finished						
22	Time of Flight measurements of micro-skimmed molecular beams	B. Holst	(Rev. Sci. Inst)	In preparation, measurements finished						
23	Center line intensities of micro-skimmed molecular beams	B. Holst	(Rev. Sci. Inst)	In preparation, measurements finished						
21	An aproach for solving the 2D and 3D self calibration	L. Matsson	(Measurement Science and Technology)	In Preparation						

Section A (public)

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
1	Conference.Talk: Phonon Dynamics of Graphene/Ru(0001)	D. Farias	European Conference on Surface Science (ECOSS-30)	31/08/2014-05/09/2014	Antalya, Turkey	Scientific	100-200	European
2	Conference Poster: Development of Graphene Mirrors for Scanning Neutral Helium Microscopy	D. Farias	10th International Conference on Diffusion in Solids and Liquids, DSL-2014	23/06/2014-27/06/2014	Paris, France	Scientific	50-100	International
3	Invited Conference Talk: Molecular beam studies of the dissociation of H2 and O2 on metal surfaces	D. Farias	2nd International workshop on scattering of atoms and molecules from surfaces	04/11/2013	Potsdam, Germany	Scientific	60	International
4	Conference Poster: Graphene Surfaces as Mirrors for Scanning Neutral Helium Microscopy	D. Farias	Hayashi conference: Next decades of Surface Science	16/07/2013-20/07/2013	Hayama, Japan	Scientific	50-100	International
5	Invited Conference Talk: Helium Diffraction and Low-Energy Phonon Dynamics of Graphene on Metals	D. Farias	Symposium on Dynamics at Surfaces	20-23/05/2015	Schloss Ringberg (Germany)	Scientific	50-100	Germany

6	Invited Conference Talk: Low-energy excitations of graphene on Ru(0001)	D. Farias	Surface Plasmons and Plasmonics Workshop	7-11/06/2015	Santa Margarita, Italia	Scientific	50-100	International
7	Invited Conference Talk: Epitaxial Graphene: the Ultimate Mirror for Scanning Neutral Helium Microscopy?	D. Farias	XXIV Int. Symposium on Molecular Beams	30/06/2015-3/07/2015	Segovia, Spain	Scientific	50-100	International
8	Conference.Talk: Helium diffraction from graphene grown by chemical vapor deposition on copper catalysts	D. Farias	15th Int. Congress on Vibrations at Surfaces	21-29/06/2015	San Sebastian, Spain	Scientific	80	International
9	Conference.Poster: Surface Structure and Acoustic Phonon Dynamics of graphene on Ni(111)	A.Al Taleb	15th Int. Congress on Vibrations at Surfaces	21-29/06/2015	San Sebastian, Spain	Scientific	80	International
10	Conference Poster: High-quality graphene on sapphire grown in UHV	G. Anemone	European Conference on Surface Science (ECOSS-31)	31/08/2015-04/09/2015	Barcelona, Spain	Scientific	100-200	International
11	Conference Poster: High-quality graphene on sapphire grown in UHV	G. Anemone	Gordon Research Conference: Dynamics at Surfaces	9-27/08/2015	Newport, USA	Scientific	70	International
12	Conference Poster: Quality of graphene on sapphire: long range order from helium diffraction versus lattice defects from Raman spectroscopy	G. Anemone	The Summer School on nanoScience@Surfaces	01-04/08/16	Cambridge, UK	Scientific	60	International
13	Conference Poster: Epitaxial Graphene: The	A.Al Taleb	The Summer School on nanoScience@Surfaces	01-04/08/16	Cambridge, UK	Scientific	60	International

	Ultimate Mirror for Scanning Neutral Helium Microscopy?							
14	Invited Conference Talk: Phonon dynamics of graphene on metals	D. Farias	3rd International Workshop on scattering of atoms and molecules from surfaces	22-26/08/16	Bergen, Norway	Scientific	50	International
15	Conference Poster: High-quality graphene on sapphire grown in UHV	G. Anemone	3rd International Workshop on scattering of atoms and molecules from surfaces	22-26/08/16	Bergen, Norway	Scientific	50	International
16	Conference Poster: Epitaxial Graphene: The Ultimate Mirror for Scanning Neutral Helium Microscopy?	A.Al Taleb	3rd International Workshop on scattering of atoms and molecules from surfaces	22-26/08/16	Bergen, Norway	Scientific	50	International
17	Conferenc Poster: Neutral Atom Microscopy	D. J. Ward	19th International Vacuum Congress	9-13/09/13	Paris, France	Scientific	500	International
18	Talk: Neutral Atom Microscopy	D. J. Ward	Advanced Materials for Demanding Applications	7-9/04/14	St. Asaph UK	Scientific	100-200	European/International
12	Talk: NEMI	D. J. Ward	Advanced Materials for Demanding Applications	12-13/12/13	Warwick, UK	Scientific	100-200	European/International
13	Poster: Neutral atom Microscopy	D. J. Ward	European Conference on Surface Science	31/08/14-05/09/14	Antalya, Turkey	Scientific	100-200	European/International
14	Talk: Neutral atom microscopy	D. J. Ward	3rd International Workshop on scattering of atoms and molecules from surfaces	22-26/08/16	Bergen, Norway	Scientific	50	International
15	Talk: Setting up a metrological traceable Mueller Polarimeter	P.-E. Hansen	8th Workshop on Ellipsometry	10 to 12'th March 2014	Dresden, Germany	Scientific	100-200	European/International
16	Invited Talk: Polarization	P.-E.	E-MRS 2014 SPRING	26 to 30 May	Lille,	Scientific	>3000	International

	dependent measurements of nanostructured surfaces	Hansen	MEETING	2014	France			
17	Poster: Mueller Matrix ellipsometry and Scatterometry: Simulation, Measurement and Analysis of Nano-textured Surfaces	P.-E. Hansen	7th International Conference on Spectroscopic Ellipsometry	2016	Berlin, Germany	Scientific	~500	International
	Talk: Seeing with atoms: The neutral microscope NEMI	*T. Kaltenbacher*	*Scattering of atoms and molecules from surfaces 2 (Sams.-2)*	*2013*	Potsdam, Germany	*Scientific*	60	*International*
	Article in popular press: Advances in Engineering	*KTH/Peter Ekberg*	*A new general approach for solving the self-calibration problem on large area 2D ultra-precision coordinate measurement machines*	*21 August 2014*		*Scientific community + Industry*		*All*
	Flyer, supported by KTH Innovation	*KTH/Peter Ekberg*	*SelfCal - software/service for self-calibration*	*29 April 2015*				*All*
	Exhibition + Flyer distribution	*KTH/Lars Mattsson*	*Control 2015*	*5 May 2015*	*Stuttgart*	*Industry*	*> 3000 / 20*	*All*
	Conference	*KTH/Peter Ekberg*	*Euspen 2015*	*1-5 June 2015*	*Löven*	*Scientific community + Industry*	*500*	*All*
	Conference	*KTH/Lars Mattsson*	*EuroNano Forum*	*10-12 June 2015*	*Riga*	*Scientific community*	*700*	All
	Workshop	*KTH/Lars Mattsson*	*ISO SIS WG6*	*17 March 2015*	*Skövde*	*Industry*	*10*	*Sweden*
	Workshop	*KTH/Lars*	ISO SIS WG6	*13 October 2015*	*Stockholm*	*Industry*	*15*	*Sweden*

		Mattsson						
	Workshop	*KTH/Lars Mattsson*	*ISO SIS WG5*	*14 October 2015*	*Stockholm*	*Industry*	*15*	*Sweden*
	Presentation	*KTH/Peter Ekberg*	*A new 2D-self-calibration method with large freedom and high-precision performance for imaging metrology devices*	*February 2016*	*Univ of Nottingham*	*Scientific community*	*40*	*UK*
	Presentation, initiated by KTH Innovation	*KTH/Peter Ekberg*	*Self-calibration applied to industry applications*	*1 April 2016*	*SP, Borås*	*Industry, Metrology experts*	*10*	*Sweden*
	Presentation, initiated by KTH Innovation	*KTH/Peter Ekberg*	*Self-calibration applied to industry applications*	*25 April 2016*	*SKF, Gothenburg*	*Industry*	*8*	*Sweden*
	Presentation, initiated by KTH Innovation	*KTH/Peter Ekberg*	*Self-calibration applied to industry applications*	*18 May 2016*	*Sandvik, Sandviken*	*Industry*	*6*	*Sweden*
	Web advertisment based on Flyer byTechnical Optics LLC - Tucson, Arizona	*KTH/Peter Ekberg by way of Matt Novak*	*SelfCal - software/service for self-calibration*	*September 2016 -*	*Tucson, Arizona*	*Industry and Research*		*USA*

Section B

The applications for patents, trademarks, registered designs, etc. shall be listed according to the template B1 provided hereafter.

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)
Patent	No		WO2016/026963	Neutral atom or molecule detector	MB-Scientific
Patent	NO		PA 2014 00432 DK	Multispectral scatterometer imaging system	Dansk Metrologisk Institut
Patent	No		GB 1619117.3	Optimisation method for microscope resolution	Universitetet i Bergen

Part B2

Please complete the table hereafter:

Type of Exploitable Foreground	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Commercial exploitation	*Helium Microscope Design*	*No*		*Helium Microscope*	*Research and standardisation tool*	*2018*	*Paten submitted, see above*	*MB, UiB, possibly UAM*
COMMERCIAL EXPLOITATION	IMPROVED SURFACE COATINGS	YES	-	TOOLS USED IN PRODUCTION	MEDICAL AND OTHERS	2016		KW
COMMERCIAL EXPLOITATION	ANTIREFLECTIVE SURFACE STRUCTURING	YES	-	SOLAR CELLS, PHOTODETECTORS, LIGHT-EMITTING DIODES, FLAT PANEL DISPLAYS	DIFFERENT SECTORS	2017		NILT
COMMERCIAL EXPLOITATION	SCATTEROSCOPE	NO						DFM
GENERAL ADVANCEMENT OF KNOWLEDGE	GRAPHENE COATINGS	NO		ULTRA-SMOOTH GRAPHENE CURVED MIRRORS; ANTI-ICING WINDOWS	RESEARCH, HELIUM MICROSCOPY (MIRROR)	2017		UAM
GENERAL ADVANCEMENT OF KNOWLEDGE	ATOM SIEVE	NO		RESEARCH, HELIUM MICROSCOPE	RESEARCH AND STANDARDISATION TOOL	2017		UIB
GENERAL ADVANCEMENT OF KNOWLEDGE	HELIUM DETECTOR (CAM)	NO		RESEARCH, HELIUM MICROSCOPE	RESEARCH AND STANDARDISATION TOOL	2017		CAM
COMMERCIAL EXPLOITATION	HELIUM HELIUM DETECTOR (MB)	NO		HELIUM MICROSCOPE, INCORPORATION IN HELIUM ION MICROSCOPE	RESEARCH AND STANDARDISATION TOOL			MB

Type of Exploitable Foreground	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
COMMERCIAL EXPLOITATION	SELF CALIBRATION SOFTWARE	NO		SOFTWARE	MICROSCOPY AND PRODUCTION INDUSTRY	2017		KTH

Helium microscope design and Helium detector (UiB and MB).

We now have the knowhow to design the best possible NEMI instrument. This knowhow consists of a helium detector design 4-5 orders of magnitude better than existing detectors and an optimisation method for designing the microscope with the highest intensity. Both detector and optimisation method are in the process of being patent protected, applications have been submitted by MB and UiB. Partner MB scientific is on the way to launch a commercial NEMI instrument. This will be developed together with UiB and it is also planned to involve KTH (self calibration) and DFM (reference metrology). If UAM succeed in improving the mirror this will also be included in a microscope design. A Eurostar application is planned for 2017. In addition we will look for good end users by contact to industry and visits to relevant conferences. Planned is, among others, to attend: International Conference on Frontiers of Characterisationd and Metrology for Nanoelectronics (FCMN 2017).

In addition contact has been made with Zeiss helium microscopy development department through director John Notte. It is now planned to do tests next year to test the use of the MB detector for detecting neutral, backscattered helium atoms in the Zeiss helium microscope. This could be an additional, commercial product for MB.

Helium detector (CAM)

The cam detector cannot be patented since it is based on ideas that have already been published in the literature. However, CAM plans to carry on its activity in helium microscopy and a research application to the British Research Council is currently in planning. A close contact has been established between the three major helium microscopy players in University research: The group of Paul Dastoor in Newcastle together with UiB and CAM. We are acutely aware that cooperation is a must if this technique is to succeed. We all support the commercial efforts of MB and on the other hand, high profile publications from the CAM and Newcastle microscopes is the best possible advertisement for MB. The three university research partners have agreed to get together for a skype meeting every three months and a helium microscopy workshop is in planning for next year.

Anti Reflective Surface Structuring (NILT)

During the last six months of the NEMI project, NILT has developed nanostructures with anti-reflective functionality when replicated in polymers. The nanostructures have been produced in silicon which can be replicated into nickel stamps. The silicon and nickel stamps have been imprinted into polymer films to give the polymer surface anti-reflective properties. The nickel stamp can also be used for injection moulding and thereby high volume manufacturing of polymeric anti-reflective surfaces.

DFM has characterized the optical properties of the nanostructures using spectral transmittance and reflectance measurements at different angles and the geometrical properties have been characterized by AFM. It has been essential for NILT to be able to link the geometrical characteristics of the nanostructures in silicon, nickel and polymer to the optical performance of the structured polymer. The optical measurements have shown that the NILT samples have a lower reflectivity for large angle of incident light compared to standard commercial anti-reflective surfaces. This is an advantage for surfaces that require an anti-reflective surface with small angular dependence. Reduced reflectance can significantly improve the optical properties in terms of reducing glare. Normally, anti-reflective surfaces are produced by applying a multi-layer coating on the surface. Anti-reflective coatings are often expensive and only reduce the reflection at a specific wavelength and incident angle.

Anti-reflective surfaces are also found in nature, where the eyes of nocturnal insects such as moths have effective anti-reflective properties, which can increase light transmission under dark conditions significantly. Instead of a coating, the moth´s eye has a nanostructure that increase light transmission for a large range of wavelengths and incident angles. Thus, by nanostructuring a polymeric surface it is possible to achieve broadband and omnidirectional anti-reflection.

For many applications, reducing the reflection and improving the transmission or absorption of light from wide angles of incidence in a broad wavelength range are crucial for enhancing the performance of solar cells, photodetectors, light-emitting diodes (LED) and flat panel displays. For many of these applications it would be highly desirable if anti-reflective nanostructures could be produced at an industrial scale at a very low cost NILT have recently experienced a technological breakthrough as we have developed a method that allow for nanostructuration of a bulk steel injection moulding tool insert with structures with lateral dimensions below 100 nm. NILT has also demonstrated replication of the structures by injection moulding used for mass production of polymeric parts. This breakthrough in combination with the promising results from the nanostructured anti-reflective surfaces developed in the NEMI project opens up new market opportunities for NILT.

To exploit these results NILT will make data sheets, update the webpage, attend conferences and tradeshows, and approach potential customers. NILT are already in dialogue with the first customer for this technology. The method for nanostructuration of a metal insert has already been patented by the Technical University of Denmark, with NILT as co-authors.

Ultra-smooth graphene curved mirrors (UAM)

During the NEMI project, UAM has developed a method to prepare graphene-coated mirrors on top of curved fused silica substrates. The key element is the use of the laser polishing technique on the fused silica curved substrate prior to deposition of the metallic coating. The subsequently increase of the coating crystallinity leads to the observation of high reflectivity to He beams. This is a remarkable result, which can have important applications in the following two areas:

1-Detection of energetic neutral atoms (ENA) in space research:

ENA imaging, often described as "seeing with atoms", is a technology used to create global images of otherwise invisible phenomena in the magnetospheres of planets and throughout the heliosphere. Interstellar Boundary Explorer (IBEX) is a NASA satellite that is making a map of the boundary between the Solar System and interstellar space. IBEX is collecting ENA emissions that are traveling through the Solar System to Earth that cannot be measured by conventional telescopes. Our mirrors, if mounted in a grazing incidence geometry (similar to the one used in the Wolter telescope) can allow detection of hydrogen and helium atoms with a much higher efficiency than current detectors. We have started contacts to see the viability of this project.

2-Lenses for solar cells:

Recent work has shown that a concave Si single crystal prepared by mechanical polishing combined with a small conventional solar cell leads to an efficiency of 16%. Our mirrors have the potential to surpass this value, since fused silica is much easier (and cheaper) to polish than silicon. In addition, different geometries can be used, with metallic or semiconducting coatings on top.

Graphene on sapphire windows (UAM)

UAM has developed, within NEMI, a method to produce in UHV (ultra-high-vacuum) good quality graphene/sapphire samples, with a high transparency to visible light (80%). These samples are stable against ambient and variable temperature environments. The preparation procedure requires evaporation of the intermediate Cu buffer layer by heating. We are currently trying to improve the method by using a pulsed laser beam instead. This can lead to important applications as anti-icing windows for optics-based technology, also as transparent conductors for the industry, as alternative to elements that are expensive and/or in short supply like indium tin oxide (ITO).

Scatteroscope (DFM)

The imaging scatterometer is an instrument that uses imaging technologies for measuring the scattered light from nanotextured surfaces. The advantages of imaging technology over the standard non-imaging technology are:

- It is possible to perform the measurement with diffraction limited resolution
- It is possible to avoid the influence of defects in the measurement results
- It is much more user friendly

Nanostructured surface are appearing in more and more device, since the nanostructure is able to improve the functionality of the device. However, there is currently a lack of quality inspection instrument for in-line quality control during the fabrication process. The scatterometer has the potential of fulfilling this demand for fast user friendly in line quality control of nanotextured surfaces. DFM will investigate the market potential for the scatterometer at conferences, through webpages and approach potential customers. DFM are currently in contact with one customer for this technology.

Improved surface coatings (KW)

At the beginning of this project KW focused on a particular challenge related to the mould of a tube with an inner thread. There were great problems related to this mould because the parts were deformed when they were extracted. In parallel with NEMI we joined the Eurostar project super slip (granted shortly after the NEMI project) which was aiming at developing coatings with particular good properties for plastic. Using the metrology work done in the NEMI project we managed to firstly gain very important knowledge about roughness related issues when applying the coatings. This meant that we can now in certain cases increase the production by 50% before we have to change the mould and we can now extract the parts from the mould referred to about without any deformation. More geometries and several plast materials were tested in the last part of the NEMI project with very promising results. The improved coatings developed through the NEMI project in synergy with Super Slip are crucial for securing the company competitiveness in a very tough international market. After the NEMI project we find ourselves in a significantly better position to do so.

Self calibration software (KTH)

During the NEMI project the already existing self-calibration concept developed several years ago at the Swedish company Micronic Laser Systems AB have been further developed for handling the more general case of using ordinary camera and micro scope images. This development has led to a an standalone calibration software to be used for any kind of calibration task of mechanical or optical metrology instruments when traceable standards with sufficient accuracy does not exist or are too expensive to develop and/or to purchase. Only the "meter" scale needs to be calibrated and made traceable in one dimension which is a much simpler task compared to the calibration of the spatial form deviations in a metrology tool in two or three dimensions using the traditional methods, when two or three dimensional traceable artifacts are needed. The new software has been successfully used in calibration of large area camera based systems (1.4 x 1.4 meter field of views) down to micro meter levels and for the calibration of White light interferometer systems and confocal micro scopes down to Nano meter levels. The use of the algorithms for these types of applications will be further explored.

Self-calibration methods are not yet a fully accepted way for calibration of metrology tools. Nor is the methods not yet supported by standards in the area. But work has been done and will be further intensified in order to convince the metrological community and industry of the advantage of using the methods both for accuracy and economic reasons. This will hopefully lead to new more modern standards for the calibration of both optical and mechanical metrology tools in the future. Cooperation with the University of Nottingham has already started of the implementation of a new approach using self-calibration that relaxes the demands of the artifact used in the process even further.

4.1 Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*

Grant Agreement Number:	309672
Title of Project:	NEMI
Name and Title of Coordinator:	Professor Dr. Bodil Holst

B Ethics

1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No***
2. Please indicate whether your project involved any of the following issues (tick box) :	***YES***
RESEARCH ON HUMANS	
• Did the project involve children?	
• Did the project involve patients?	
• Did the project involve persons not able to give consent?	
• Did the project involve adult healthy volunteers?	
• Did the project involve Human genetic material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	
• Did the project involve Human Foetal Tissue / Cells?	
• Did the project involve Human Embryonic Stem Cells (hESCs)?	
• Did the project on human Embryonic Stem Cells involve cells in culture?	
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
• Did the project involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	
• Were those animals transgenic small laboratory animals?	
• Were those animals transgenic farm animals?	

- Were those animals cloned farm animals?	
- Were those animals non-human primates?	
RESEARCH INVOLVING DEVELOPING COUNTRIES	
- Did the project involve the use of local resources (genetic, animal, plant etc)?	
- Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
- Research having direct military use	0 Yes 0 No
- Research having the potential for terrorist abuse	

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	1	
Work package leaders	2	5
Experienced researchers (i.e. PhD holders)	2	9
PhD Students	1	1
Other		

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**5**
Of which, indicate the number of men:	3

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?	○ x	Yes No

6. Which of the following actions did you carry out and how effective were they?

		Not at all effective				Very effective
☐	Design and implement an equal opportunity policy	○	○	○	○	○
☐	Set targets to achieve a gender balance in the workforce	○	○	○	○	○
☐	Organise conferences and workshops on gender	○	○	○	○	○
☐	Actions to improve work-life balance	○	○	○	○	○

○ Other:

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

x No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

x Yes- please specify - Master students were educated (UiB) science open day (CAM)

○ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

○ Yes- please specify

x No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

○ Main discipline[2]: 1.2

○ Associated discipline[2]:2.3 ○ Associated discipline[2]:

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*	x ○	Yes No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

x No

○ Yes- in determining what research should be performed

○ Yes - in implementing the research

○ Yes, in communicating /disseminating / using the results of the project

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[2] Insert number from list below (Frascati Manual).

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ ○	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

x No
○ Yes- in framing the research agenda
○ Yes - in implementing the research agenda
○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
x Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
○ No

13b If Yes, in which fields?

Agriculture		Energy		Human rights	
Audiovisual and Media		Enlargement		Information Society	
Budget		Enterprise		Institutional affairs	
Competition		Environment		Internal Market	
Consumers		External Relations		Justice, freedom and security	
Culture		External Trade		Public Health	
Customs		Fisheries and Maritime Affairs		Regional Policy	
Development Economic and		Food Safety		Research and Innovation	
Monetary Affairs		Foreign and Security Policy		Space	x
Education, Training, Youth		Fraud		Taxation	
Employment and Social Affairs		Humanitarian aid		Transport	

13c If Yes, at which level?

○ Local / regional levels
○ National level
○ European level
x International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**13 (more in preparation)**
To how many of these is open access[3] provided?	**2**
How many of these are published in open access journals?	**2**
How many of these are published in open repositories?	**2**
To how many of these is open access not provided?	**11**
Please check all applicable reasons for not providing open access:	
☐ publisher's licensing agreement would not permit publishing in a repository ☐ no suitable repository available ☐ no suitable open access journal available x no funds available to publish in an open access journal ☐ lack of time and resources ☐ lack of information on open access ☐ other[4]: ……………	
15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*	**3**

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	
	Registered design	
	Other	

17. How many spin-off companies were created / are planned as a direct result of the project?	**1**
Indicate the approximate number of additional jobs in these companies:	

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

☐ Increase in employment, or
☐ Safeguard employment, or
☐ Decrease in employment,
x Difficult to estimate / not possible to quantify

☐ In small & medium-sized enterprises
☐ In large companies
☐ None of the above / not relevant to the project

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:* *29.9 FTE*

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[3] Open Access is defined as free of charge access for anyone via Internet.

[4] For instance: classification for security project.

Difficult to estimate / not possible to quantify	☐

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

x Yes ○ No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes x No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

☐ Press Release
☐ Media briefing
☐ TV coverage / report
☐ Radio coverage / report
☐ Brochures /posters / flyers
☐ DVD /Film /Multimedia

x Coverage in specialist press
☐ Coverage in general (non-specialist) press
☐ Coverage in national press
☐ Coverage in international press
☐ Website for the general public / internet
☐ Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

x Language of the coordinator
☐ Other language(s)

☐ English

Question F-10: Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES
1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]
1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)
1.3 Chemical sciences (chemistry, other allied subjects)
1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)
1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY
2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)
2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]
2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as

geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)
3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)
3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)
4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology
5.2 Economics
5.3 Educational sciences (education and training and other allied subjects)
5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)
6.2 Languages and literature (ancient and modern)
6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]