DeMaMech Exchange Program Report

Sep. 2004 – Jan. 2005

Technical University of Denmark (DTU)

Masaki Michihata

1. Personal Data

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Supervisor : Takashi Miyoshi

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Supervisor : Leonardo de Chiffre, Joergen Garnaes

2. Executive Summary (max 1 page)

I studied at Technical University of Denmark (DTU) for 5 months from September 2004 to January 2005. During the period, I was doing one project, 2 regular courses and one extra course (English course).

During whole the period, I was doing one project under my supervisor at DFM which is based on DTU and IPL which is one department belonging to DTU. My topic is deeply related to Atomic Force Microscopy (AFM). AFM has been already a matured tool for investigation in a field of nano/micro technology. However, it's still held some problems. One of the most serious problems is convolution of a tip shape of AFM cantilever and sample surface topography. My study aims to extract the contribution of the tip shape to AFM image. For that purpose, two kinds of samples called tip characterizer were used. These samples have sharp peaks on them, which have potential to reveal tip shape accuracy up to around 30nm from the end of the tip edge. So the images of those characterizers were analyzed by using two kinds of methods, Blind Reconstruction and Direct Estimation, according to situations with commercial computer software, Scanning Probe Image Processor (SPIP). The conclusion is such as the following. The AFM tip seems to have an extremely small radius of curvature in a range from the very end of tip to around a few nanometers, approximately 20 nm radius of curvature in the range between 5 nm to 15 nm from the tip edge and straight line upward form that.

In the period from September 2004 to December 2004, which means the period of fall semester, I was taking two regular courses, Introduction to industrial environmental management, CAD/CAM, and extra course, English course. In both of regular course, I had group works. Group work is sometimes quite effective, but sometimes quite troublesome, as you can image. So we could learn many things from group works. Each course has exercise every week either. So we had to study constantly, otherwise it's impossible to catch up with the lecture proceedings.

As my study environment, my accommodation was a student dormitory located inside of the campus. This dormitory accommodates about 100 foreign students. This accommodation was pretty good place for making friends and learn communal life, because we must have shared same equipments such as kitchen, shower room, and toilet for 10 people. For solving some conflict, we needed to talk often and understand each other. It was good experience to me. As other activities, I could enjoy parties, sports and sightseeing, etc.

3. Travel Schedule

Period : September 2004 – January 2005

4. Research or Lectures

In Denmark, I was doing one project and 3 courses. The project was done under my supervisor of Denmark. 3 courses were 2 regular courses and one English course.

My project was done at DFM. On weekday, I studied my project there at from 10 to 5 except time for classes. Content of my project is such as the following.
Under invisible scale technology or atomic scale technology called the Nanotechnology, at present many kinds of technology have been developing. One of key technologies is absolutely optical technology. Its physical scale of components has been already reached the scale much less than light wavelength.
It is always necessary to measure geometrical parameters such as dimension, roughness, etc. for guaranteeing functionality or performance of products or components. However, it is not an easy task to evaluate the accurate shapes at nanometer scale, especially when they have complicated shapes like an undercut structure, a high aspect ratio and so on.
Atomic Force Microscope (AFM) was utilized in this study, which has a high resolution and adaptabilities with many kinds of samples. Here the principal of AFM is explained. As the name indicates, AFM uses the atomic force between the end of the AFM tip and sample surface. AFM cantilever, which consists of a substrate and a very sharp tip, is oscillated (in case of tapping mode) and getting close to a sample surface, and then the atomic force caused by Van der Waals attraction works between the tip and the sample when the distance between them is adequately small. The Atomic force influences a condition of cantilever oscillation, that is, its amplitude, frequency and so on are shifted. The shift can be detected as shown in the following figure. The incident light (typically laser) hits a back face of the cantilever substrate, and then reflects. Reflected light enters a detector. The light path would shift with the change of cantilever oscillation.

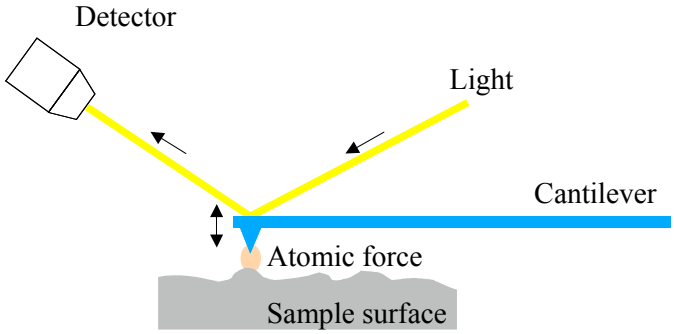
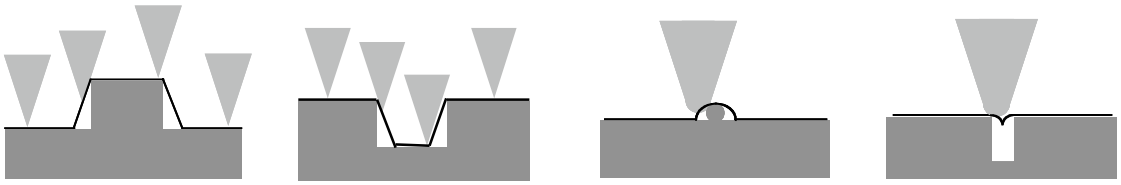


Fig. 1 The principal of Atomic Force Microscope.

AFM has already matured in some ways, but still has some problems, one of which is a convolution of the tip and a sample surface. Figure 2 depicts concrete situations.



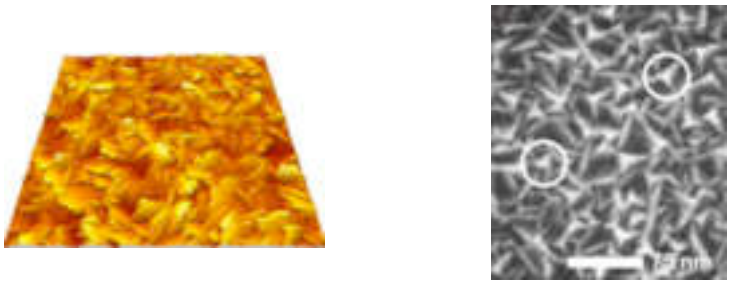
(a) Protrusion (b) Pocket (c) Particle (d) hole

Fig. 2 Influences of tip – sample convolution.

Figure 2 (a) and (b) show influences risen a finite tip shape. An artificial AFM tip cannot vanish, so that these problems are unwanted company. Due to specific cone angle of AFM tip, the tip cannot reach roots of protrusion or bottom corners. Figure 2 (c) and (d) show cases that sample surface has smaller structures than the radius of curvature of AFM tip. In (c), tip cannot trace the small particle because the particle is too small. In (d), the tip cannot be go into the hole due to small width hole. In this case, AFM is able to detect that there exist a something. This problems cause a distortion, bluer of AFM images. The images involved such kinds of problems cannot be reliable images. So the problems must be solved. The only way to solve them is to know the tip shape exactly. Therefore, in order to obtain as accurate images as possible, the tip shape has to be known. As a result, after taking AFM images, the tip shape can be extracted from the AFM images.

Thus in this project, the AFM tip characterization was deeply focused on as preparative study of measuring practical structures such as optical components.

Tip characterization was implemented with two kinds of tip characterization sample, called TipCheck and NioProbe, by using two kinds of method, called blind reconstruction and named direct estimation. Two characterization samples are called tip characterizers. Necessaries as a tip characterizer are hardness, sharp peak, and random orientation. Tip check and NioProbe can meet these requirements, because they are made of hard crystal. From the images of them shown in figure 3, it's known that they have completely random oriented peak. And according to the company which makes these samples, peaks on NioProbe sample have less than 5 nm radii. Thus, TipCheck and NioProbe are regarded as appropriate tip characterizer for AFM tips. The AFM images were analyzed based on two kinds of methods, Blind reconstruction and direct estimation. Blind reconstruction is a mathematical method that takes into account all peaks or valleys over the image, so that all processes are carried out with a computer



(a) TipCheck from AFM (b) NioProbe from SEM

Fig.3 Tip characterizer.

software called SPIP (Scanning Probe Image Processor). SPIP works out a tip image estimation by using blind reconstruction.

It was expected that tip shape could be evaluated up to 30 nm from the end of tip.

As a conclusion, each tip has been revealed the shape from both characterization samples although its value includes specific uncertainly. And each tip has each shape, which may be not able to be assumed as a simple model by being evaluated at a nanometer scale. Direct estimation is simple method. As you can image from figure 2 (c), when a tip traces a small part, the radius on AFM, $R_{profile}$, image is made from a radius of a tip edge, R_{tip}, and a radius of a sample peak, R_{sample}. This relation can be express simple formula such the following,

$$R_{profile} = R_{tip} + R_{sample}$$

Based on abovementioned principal, experiments and analysis were implemented.

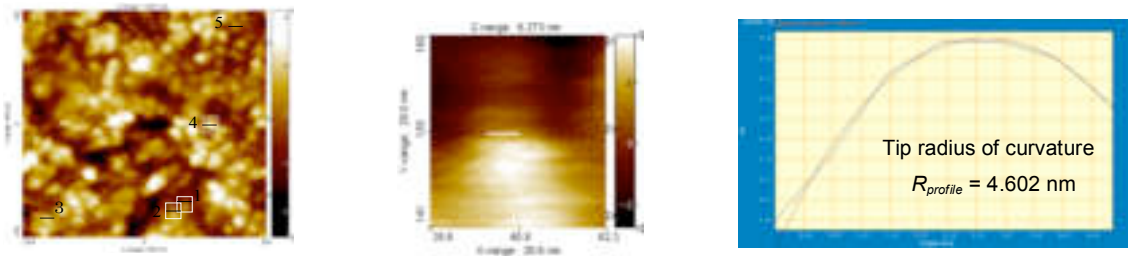
Figure 4 shows one result from TipCheck sample, an estimated tip shape based on the image by using blind reconstruction, and its cross-section profile.

(a) TipCheck image (b) Estimated tip shape (c) Estimated tip shape profile

Fig.4 One result of TipCheck sample.

Figure 5 shows one result from NioProbe. (a) is full image from AFM. Numbers and

squares means picked up peaks, because the five sharpest peaks were referred as presenting peaks among all of peaks in an image. (b) is one of peak and (c) show the profile.



(a) NioProbe image (b) one peak (c) profile of the peak.

Fig.5 One result of NioProbe smaple.

From those results, tip shape was investigated. But tip shapes are no longer same with all other tips, because the domain has reached nanometer scale. So each single tip has to be evaluated in cases of developed investigation. Now this study is still basic study, so that the shapes were tried achieving normalization. Figure 6 is the conclusion.

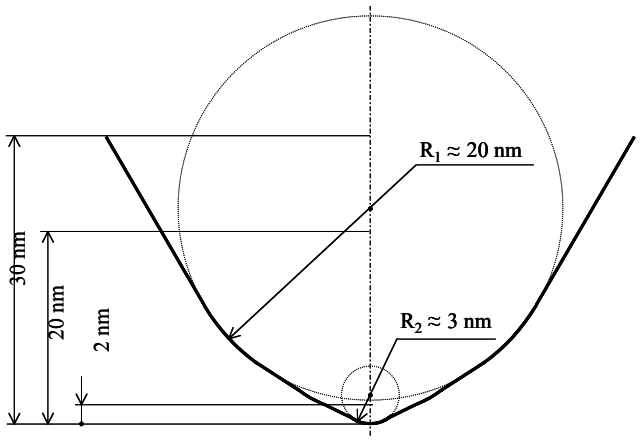


Fig.6 Result of analysis.

From figure 4, it's seen that a tip has approximately 20 nm radius of curvature in the range between 5 nm to 15 nm from the tip edge and has straight line upward form that. From figure 5, tip has an extremely small radius of curvature in a range from the very end of tip to around a few nanometers. These data were combined and result in figure 6.

About courses, I was taking two regular courses although any credits are not necessary for me as a matter of fact.
One of them is CAD/CAM course which is for foreign students and students without previous experience in Pro/Engineer. This course was held from 8 to 12 on Thursdays and was composed of Lectures and exercises. All of exercise were done with group of two students.
In this course, I learned to create models of machine parts and assemblies of these using a CAD-system and a graphical workstation and use computer aided systems (CAD/CAM systems) in process planning. In terms of contents, as exercise for CAD system, there were geometric modeling, solid modeling, surface description, Boolean operations on solid models, transfer to drafting programs, dimensioning, programming in CAD-systems, and assembly of solid models to systems, and as a part of CAM or practical task by using machining tool, there were exercises such as introduction to numerically controlled machine tools, CAM and NC-programming, computer aided process planning (CAPP), reverse engineering and rapid prototyping and tooling. Especially, we made a model of LEGO human for CAD exercise.
After finishing all of exercise, we started to work on final report which is consist of theoretical part and practical part. Our theme was CAPP.

Another is Introduction to Industrial Environmental Management. This course was held from 13 to 17 on Tuesdays and consisted of lectures and project. The Projects were based on groupwork.
In this course, I learned planning, implementation and control of the environmental and work environmental activities in a company and obtained knowledge and skills enabling them to develop and implement environmental and work environmental management, apart from knowledge of structural elements in industrial environmental management. Besides, we dealt with how it can be integrated as a part of other activities in the company.
As final project, we made a report that is about comparing Danish 4 companies in respect to strategic management and formulation of environmental and work environmental strategies, design and implementation of environmental and work environmental management, and certification and audit of environmental and work environmental management systems.

The last is the English course. This is not regular course and is opened for foreign students who want to improve their English. I took this course from 5 to 8 on Mondays

and Wednesdays.

This course was concentrated on speaking English. Contents of the lecture were vocabulary, pronunciation, grammar, reading, and discussion. This course is not for any credits, so that there was no examination, no evaluation.

5. Exchange student life (max 2 pages)

My life at DTU was completely different from one in Japan. Only same thing is to go to school everyday.

First of all, I describe my room in Denmark as life environment. My room was inside of a Campus, called “Campus village”. Campus village is consists of ten buildings (it’s just container), and about 100 students live there, that is, each container includes around 10 people. We had to share a kitchen, shower room, and toilet for 10 people. Since I’d never lived alone before coming to Denmark, almost all things such as cooking, washing my clothes were special for me. But many students were same situation as me, so we often helped each other when we had some troubles. Of course we have some trouble with each other because many people live together and we were not only unfamiliar with each other at the beginning, but also different nationalities people. In case of our container, there were Chinese, Spanish, Turkish, Pakistani, Italian, French, Bulgarian and, of course Japanese, totally 8 countries. For enjoying our exchange life and knowing of each other, we sometimes had parties, and then cooked own countries’ dishes and showed off them to others.

Basically, I was taking 2 courses and English course, and doing one project. So all weekdays of daytime and evening until 6 or 7 o’clock were occupied by them. In the evening, normally I did study, cooking, chatting with friends, sports, going to parties etc. In DTU, there were parties at least one or twice a month. Some of them were organized by DTU or PF, which is also organization in DTU. In their parties, there were concerts, bars, disco, and so on. Usually many Danish students, International students and foreign exchange students joined it. Perhaps, I can say it’s the biggest party in DTU. Some other parties were organized by some communities. For example, there were Spanish, Korean, Italian, and French parties during that semester. They invited a lot of students and prepared their own countries’ foods or dishes for guests. We could enjoy many different countries taste there. But it was unlikely to have Japanese party although many friends requested me to organize it. For foreigners, the most famous Japanese foods is “sushi” definitely. It’s too expensive, because I have to prepare for it for about 50 people at least, beside there were not many Japanese students in DTU (There were 7 Japanese in DTU as far as I know and they didn’t know of each other). Most of the others were held with people who knows each other. Actually these were not really parties. We just cooked for our friends and ate together. Then I often cooked Japanese foods such as “Temaki-sushi” or “Okonomi-yaki” for my friends. Except parties, we hung out a bar, which is inside of DTU. Especially, Tuesday was referred as international

night. So many international students came to the bar to meet some friends. I think that to go to parties or bars is one good way to make friends. Then we could share useful information there.

As other activities, sports can be mentioned. In my case, I often played soccer. There is a huge ground for soccer or rugby. Students can use those fields freely as long as it's not occupied. Many people were playing there, international students and Danish football team as well. Sometimes I joined Danish team. In Europe, soccer is the most popular sport, as you may know. So in August, there was one competition called "DTU world cup". This was organized by PF and for international students. All international students can attend it. And then we made one team which is consisted of many nationalities people, about 8 countries. Other team was like Italian team, Spanish team, Czech team and French team. It was very excited, because they really like to play football and most people were good players. In this time, French team won, it's just like real World cup in 1998. Our team lost against Italian team. In winter, we could not play football at out door fields any more due to too cold temperature. So we moved to indoor fields. DTU offers many sports opportunities, such as football, badminton, tennis, climbing, and so on. People can enjoy sports inside of DTU. But just nearby DTU, there is also one place where we can play some sports. But we have to pay because it's not part of DTU.

6. Suggestions to the Project

I am satisfied with this exchange program except the following only one thing.
DTU has an event called introduction week for international students before a semester. It for fall semester was held on the end of August. And also the semester started the end of August. Nevertheless, I was not allowed leaving Japan until September 1st. I think it's not good. So I hope we can choose the date of departure more flexibly, which means both way going to Europe and returning to Japan according to a schedule of each university.

7. Summary

Studying at DTU was quite good experience for me.
I studied hard and tried to understand with different nationalities students, resulting in having many friends in Denmark. I learned many precious things included academic knowledge, knowledge of life and so on from the university and all of friends there.
About my project, this project was very interesting for me, but not easy task. I used approximately 1 month among 5 months for grasping how to use instruments, software and understanding what my project is. And so I could use only 4 months to investigate the topic, this was not enough periods to conclude it. However, I think the most important thing is not conclusion, to study about it, experience of studying there, and discuss with my Danish supervisor are more important.
In terms of study, each class was not easy, which means that not only we had to understand the contents of lectures (in order to catch up with lecture, we normally needed to spend own spare time to study by myself), but also we managed to work out group work. DTU is enthusiastic about having us address group work. On many courses, group work is compulsory. We had to do cooperate with other nationalities people.