Annual report 2016

FOM programme nr. i37
'The foundations for faster electron microscopy'

14x14 electron beams in a scanning electron microscope for faster imaging of large 2D biological samples or slices from a 3D volume.

May 2017
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1. Scientific results 2016

In the project on ultrafast transmission electron microscopy (U-TEM), the ultrafast TEM equipped with a TM-110 chopping cavity is operational now, delivering few picosecond pulses with conservation of peak brightness and energy spread. The first pump-probe experiments in the U-TEM are underway. In the SEM setup the Time-of-Flight (TOF) EELS technique, based on the use of two TM-110 cavities, has been demonstrated experimentally. A significantly improved version of the TOF EELS technique, employing longitudinal phase space manipulation with two additional TM-010 cavities, has been patented. A setup to demonstrate the improved TOF EELS technique has been built and first results are coming out now.

In the nano aperture ion source project, intensive cooperation between the FEI group in Hillsboro and the group in Delft resulted in the first experimental measurements of the brightness. In Hillsboro, where a version of the Delft design is incorporated in a full dual beam system, beautiful ion images were collected with the brightness of the source at about $10^4$ A/m²srV. In Delft, in a test set-up specifically for brightness measurements, a brightness of more than $10^5$ was measured for a variety of noble gas ions. With that, and the older measurements of energy spread, the properties of the source have surpassed those of the liquid metal ion source, presently the workhorse in focused ion beam machines. In parallel, the PhD student on the project has performed extensive theoretical analysis and simulations of the source properties and written his thesis. Reproducible production of gas chips is still a problem.

The multi beam project now concentrates on detection of the transmitted electron signal. An analysis of the PhD student concluded that this information is fully equivalent to the information from backscattered electrons and thus more valuable for biologists than secondary electron detection. With support from a STW project, a detection system consisting of a $10^4$ frames per second camera and an FPGA processor was developed for the read out of the 196 beams. This is now resulting in better quality images. Altogether, the programme is doing well, with a remarkably intensive contact between the scientific partners and the industry partner. In all three sub-programmes there are already plans for commercialization of the results, while the scientific output is still being produced.

2. Added value of the programme

Especially on the subject of ultrafast electron microscopy and diffraction, the programme is a great stimulus to exchange ideas between the 3 partners FEI, TUE and TUD. A direct result is the addition to the programme of a valorisation project from FOM to explore an ultrafast blanker for SEM's with cash support by FEI.

On ion beam development, there is overlap between Delft and another programme in Eindhoven where ion sources are under development.

3. Personnel

At the beginning of 2016 all PhD positions were filled, but to our regret, the youngest PhD student in FASTER 2 resigned to return to his home land. The programme committee is still deliberating on how to proceed. The vacancy in FASTER 2&3 for a technician was filled with starting date 01-01-2017 by an excellent candidate with many years of experience within FEI.

4. Publications

In FASTER 1 (14FFEM01) one paper has been published in a refereed journal and three others are in preparation: one on the patented improved TOF EELS technique, one on commissioning of the U-TEM equipped with a TM-110 chopping cavity, and one on the theory of TM-110 cavities as charged particle optical elements; all to be submitted to refereed journals soon.

14FFEM01

a. Scientific (refereed) publications
b. Presentations at (inter)national scientific conferences
- 20-01-2016, Physics@FOM Veldhoven, Wouter Verhoeven, Femtosecond electron imaging and spectroscopy.
- 15-03-2016, Plasma Lunteren, Jasper van Rens, Ultrafast electron imaging and spectroscopy.
- 08-09-2016, CMD26 - The 26th Conference of the Condensed Matter Division of the EPS, Groningen, Wouter Verhoeven, Time-of-flight EELS using RF technology.
- 12-10-2016, AMO Lunteren, Wouter Verhoeven, Ultrafast electron microscopy using RF technology.
posters:  
- 20-01-2016, Physics@FOM Veldhoven, Jasper van Rens, Ultrafast electron microscopy and diffraction.

14FFEM02
b. Presentations at (inter)national scientific conferences

14FFEM03
a. Scientific (refereed) publications

b. Presentations at (inter)national scientific conferences
- Kruit,P; Multi-electron-beam technology with applications in microscopy, inspection and lithography, EIPBN Pittsburg, 2016.

Ultrafast BLANKER valorisation grant
a. Scientific (refereed) publications

b. Presentations at (inter)national scientific conferences

5. PhD defences
None.

6. Valorisation, outreach and patents
The ultrafast electron microscope of FASTER 1, is a prototype for a commercial FEI product. A patent has been filed for FASTER 1: “Time-of-flight charged particle spectroscopy” U.S. Application No.15/364,145; inventors: W. Verhoeven, J. F. M. van Rens, E. R. Kieft, P. H. A. Mutsaers, and O. J. Luiten. For FASTER 2, several patents are in preparation. In connection with this, publication of some of the results is being delayed. For FASTER 3, a consortium is being set up in order to prepare for a commercial version of the multi beam SEM.
7. **Vacancies**

The researcher position in FASTER 2 is open after the PhD student resigned.
**APPROVED INDUSTRIAL PARTNERSHIP PROGRAMME**

**Number**
- i37.

**Title (code)**
The foundations for faster electron microscopy (FFEM)

**Executive organisational unit**
- BUW

**Programme management**
- Prof.dr.ir. P. Kruit

**Duration**
- 2013 – 2018

**Cost estimate**
- M€ 2.8

**Partner(s)**
- FEI

**Concise programme description**

*a. Objectives*

The objective of this Industrial Partnership Programme is to make major steps in the advancement of scientific knowledge and technology in the area of electron microscopy and ion beam technology. Making instrumentation faster is not just saving time for economic reasons. If the speed is increased above certain thresholds, it enables fundamentally new scientific investigations and new applications of the instruments in industry.

*b. Background, relevance and implementation*

Understanding the atomic structure of natural and man-made (bio)-components, devices and materials forms nowadays the basis for further scientific discovery and developments in nanotechnology, biotechnology, micro- & nano-electronics, (nano)photonics and new materials. This results in an increasing attention for characterization methods and equipment in nanotechnology, biotechnology and advanced materials laboratories, both in (academic) science as well as in industrial R&D labs. Electron microscopy (EM) is one of the most versatile instruments for atomic-scale imaging and analysis. Imaging modalities are coupled to chemical analysis, and sometimes also combined with focused ion-beam columns to modify samples on nm scales.

The central theme of this IPP is: the need for speed. Clearly it will be advantageous to get the same results in less time. For industry this translates directly into less cost for analysis and characterization. However, the most interesting aspect of 'faster' EM is when experiments can be done which are simply not possible in a 'slower' regime. The themes addressed in this programme have the potential to achieve exactly that.

Ultrafast EM has the potential to extend the pump-probe type of (molecular) investigations to localized dynamic experiments. Applications might range, depending on the exact way the experiments are set up, from 'freezing' molecular motion in live-cell imaging; via crack propagation and phase transitions in materials, to local time-resolved probing of the electronic and/or magnetic properties in devices.

New ion-beam sources have the potential to radically change the way we can create or modify structures at the nm-scale in three dimensions. Ion sources are important in almost all of FEI's markets, but especially in the electronics market (sample prep), and nano-prototyping. It is the strategy of FEI to explore new technologies together with outstanding academic partners, as is the case in this programme.
**Funding**

salarispeil cao tot 01-01-2016

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1) Dit bedrag is afkomstig van de extra middelen die het AB van NWO beschikbaar heeft gesteld in de propositie 2014-2015 voor de Topsector HTSM.

2) Vooruitlopend op het IPP heeft FEI een cash bijdrage geleverd van k€ 50 aan een start-up project. De totale inbreng van FEI en de samenwerking tussen FOM en FEI bedraagt daarmee k€ 1.300 in-cash, waarvan k€ 1.250 in het IPP.

3) Voor dit IPP is door het TKI HTSM een TKI-toeslag aangevraagd ter grootte van k€ 315. Deze toeslag is toegekend door RVO. Uiteindelijk is aan het programma k€ 306 toegevoegd en is k€ 9 afgedragen aan het TKI.

**Source documents and progress control**

a) Original programme proposal: FOM-13.1277
c) Decision Executive Board: FOM-13.1942
d) Contract: FOM-14.0751

**Remarks**

The final evaluation of this programme will consist of a self-evaluation initiated by the programme leader and is foreseen in 2018.
### Overview of projects and personnel

#### Workgroup FOM-D-22

**Leader**  
Prof.dr.ir. P. Kruit  
**Organisation**  
Delft University of Technology  
**Project leader(s)**  
**Project (title + number)**  
FASTER 2: New ion beams (14FFEM02)

**FOM employees on this project**

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<tr>
<th>Name</th>
<th>Position</th>
<th>Start date</th>
<th>End date</th>
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<tbody>
<tr>
<td>L. van Kouwen</td>
<td>PhD</td>
<td>1 January 2014</td>
<td>31 July 2016</td>
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<tr>
<td>D. Radovanovic</td>
<td>PhD</td>
<td>15 October 2015</td>
<td>23 October 2016</td>
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**Leader**  
Prof.dr.ir. P. Kruit  
**Organisation**  
Delft University of Technology  
**Project leader(s)**  
**Project (title + number)**  
FASTER 3: High throughput SEM by multi beam imaging (14FFEM03)

**FOM employees on this project**

<table>
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<th>Name</th>
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<th>Start date</th>
<th>End date</th>
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<tr>
<td>W. Zuidema</td>
<td>PhD</td>
<td>1 October 2015</td>
<td>30 September 2019</td>
</tr>
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#### Workgroup FOM-E-04

**Leader**  
Prof.dr.ir. O.J. Luiten  
**Organisation**  
Eindhoven University of Technology  
**Project leader(s)**  
**Project (title + number)**  
FASTER 1: Radiofrequency cavities for ultrafast electron microscopy (14FFEM01)

**FOM employees on this project**

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<tr>
<th>Name</th>
<th>Position</th>
<th>Start date</th>
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<tr>
<td>J.F.M. van Rens</td>
<td>PhD</td>
<td>6 October 2014</td>
<td>5 October 2018</td>
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<tr>
<td>W. Verhoeven</td>
<td>PhD</td>
<td>1 October 2014</td>
<td>31 July 2018</td>
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