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Networking strategies of the microscopy community for improved utilisation of advanced instruments: (3) Two European initiatives to support TEM infrastructures and promote electron microscopy over Europe, ESTEEM (2006–2011) and ESTEEM 2 (2012–2016)

Stratégies de mise en réseau élaborées par les communautés de la microscopie électronique pour optimiser l'utilisation des nouvelles plateformes instrumentales : (3) Deux initiatives européennes pour soutenir les infrastructures MET et promouvoir la microscopie électronique en Europe, ESTEEM (2006–2011) and ESTEEM 2 (2012–2016)

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A B S T R A C T

The ESTEEM consortium of electron microscopy laboratories for materials science and solid-state physics has been created as an EU-supported delocalized infrastructure (I3) to bring together the major electron microscopy centres in Europe. Its main objectives were to develop networking, to offer transnational access to these centres with specialized and complementary techniques and skills and to upgrade in close collaboration different technical and methodological aspects such as tomography, spectroscopy, holography, detectors, and specimen holders. These efforts were aimed to strengthen the position of European microscopy and to generate new technologies potentially of high relevance in many domains identified as strategic. Following the success of the first program, ESTEEM has been reconducted in 2012 for four more years with an enlarged set of partners.

R É S U M É

Le consortium de microscopie électronique dédiée à la science des matériaux et à la physique de la matière condensée (ESTEEM) a été créé comme infrastructure européenne délocalisée (I3) en regroupant quelques centres majeurs en Europe. Trois objectifs principaux lui étaient dévolus : développer des actions de mise en réseau, offrir un accès aux équipements spécialisés dans ces centres regroupant des techniques et des expertises complémentaires, et développer en collaboration étroite certains aspects technologiques ou méthodologiques, tels la tomographie, les spectroscopies, l'holographie, les détecteurs et des porte-échantillons spécifiques. Ces efforts avaient pour but de fortifier la position

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de la microscopie européenne et de générer de nouvelles technologies d'importance pour un certain nombre de domaines stratégiques. Le premier programme ayant été jugé très positif, l'infrastructure ESTEEM2 a été reconduite pour une période de quatre ans à partir de 2012.

1. The ESTEEM project (2006–2011)

In 2006, within its 6th Framework Program, the European Commission (EC) has decided to support a five-year (2006–2011) IP3 project entitled **ESTEEM** (**E**nabling **S**cience and **T**echnology through **E**uropean **E**lectron **M**icroscopy) dedicated to transmission electron microscopy (http://esteem.ua.ac.be/). The ESTEEM consortium grouped 11 of the major electron microscopy laboratories in Europe over Belgium, UK, Germany, France, The Netherlands, Spain, Slovenia, and Poland.

The main goals of the ESTEEM project were to promote and develop electron microscopy capabilities over Europe and to offer Transnational Access (TA) to the most advanced electron microscopes to the academic and industrial communities. As a result, during the five-year duration of the project, 4, 224 days of access to advanced TEM equipment have been provided to 780 users coming from all over Europe through ESTEEM Transnational Access.

Besides facilitating the access to advanced TEM equipment, the European Union aims at supporting workshops and schools to enhance the number of TEM users of the next generation and to train them in the use of quantitative and advanced TEM techniques. ESTEEM has then supported 17 TEM workshops attended by over 700 European participants.

Joint Researches Activities (JRAs) were also part of the ESTEEM project with the aim of supporting progress in the field of electron microscopy for the benefit of TEM users. The general JRAs themes were to improve three-dimensional imaging of nanoparticles down to the sub-nanometer, and possibly atomic, scale, to push the limits of chemical and electronic mapping in nanostructured materials, to develop improved detection in electron microscopy for rapid acquisition of images and spectra and to develop tools for nanomanipulation experiments inside the electron microscope and apply these tools for the study of dynamic systems. ESTEEM's JRAs were then focused on electron tomography, electron spectroscopy for mapping electronic structure, holography for mapping fields, new electron detectors developments and new TEM capabilities for *in-situ* experiments. The supported collaborative research activities between ESTEEM partners resulted in a large number of new developments. Many innovative methodologies and tools were indeed developed and cutting-edge results obtained by the ESTEEM consortium. Some of them can be highlighted, as the new algorithm for discrete tomography reconstruction [1], the first mapping of plasmons in nanostructures (Fig. 1) [2], the discovery of the "dark-field electron holography method" for mapping strain fields [3], the creation of vortex electron beams [4], the combined use of holography and tomography for mapping 3D electrostatic field in devices [5]...

These innovative results and progress in TEM techniques were transferred to the whole TEM community and most of these advanced methods developed though ESTEEM are now available for any TEM user worldwide. Within the five years of the ESTEEM activities, 256 papers have been published and 24 patents have been registered by the ESTEEM consortium.

2. From ESTEEM to ESTEEM2 (2012–2016)

A year after the ESTEEM project ended, the EU decided to support its continuation through an infrastructure (I3) four-year project within its FP7 program: **ESTEEM2** (2012–2016) (http://esteem2.eu/). Compared to ESTEEM(1), the ESTEEM2 consortium has been extended to new partners in Germany, Sweden, Austria, and Spain, and two SMEs. The general goals of ESTEEM2 are similar to the ESTEEM(1) objectives: 1) to provide open access to the most advanced equipment to the widest possible academic and industrial research community; 2) to improve and develop new advanced TEM techniques for the benefit of users, and, as an additional goal, 3) to create a sustainable infrastructure after ESTEEM2 ends. See Fig. 2.

Regrouping the equipment of 13 academic partners, European users have access, through Transnational Access (TA), to 28 of the most advanced microscopes including three double corrected microscopes, several monochromated probe corrected microscopes, few dedicated TEM for various type of *in situ* TEM experiments, a dedicated probe-corrected STEM devoted to EELS experiments, a cold-FEG microscope dedicated to holography and eight FIBs for sample preparation. About 3 400 access days are proposed to the ESTEEM2 equipment for the 4-year duration of the project.

After the five years of active developments of ESTEEM(1) in Joint Research Activities, the new consortium has decided to focus the ESTEEM2 JRAs on five main subjects slightly different from the previous JRAs with a similar aim to develop advanced quantitative TEM methods for structural, chemical, electronics, and field measurements, and to transfer these TEM improvements among partners for the benefit of the users. The first JRA concerns "Quantitative electron diffraction" developments both thanks to new electron precession capabilities but also through CBED and coherent diffraction. The second is devoted to "Imaging" both in high-resolution STEM and TEM and EFTEM. It involves the development of methods for quantification and interpretation of (S)TEM images acquired using state-of-the-art instrumentation and techniques. The third JRA is dedicated to advanced "Electron spectroscopies". Its goal is to develop new, versatile EELS techniques and methods and in particular for the study of magnetism, nano-optics and plasmonics, all of which have potential industrial applications within EU industry. The fourth is focused on the "3D nanometrology". The objective of this JRA is to obtain precise and quantitative measurements of properties, including chemical composition, magnetic fields and strain distributions, in 3D and in some

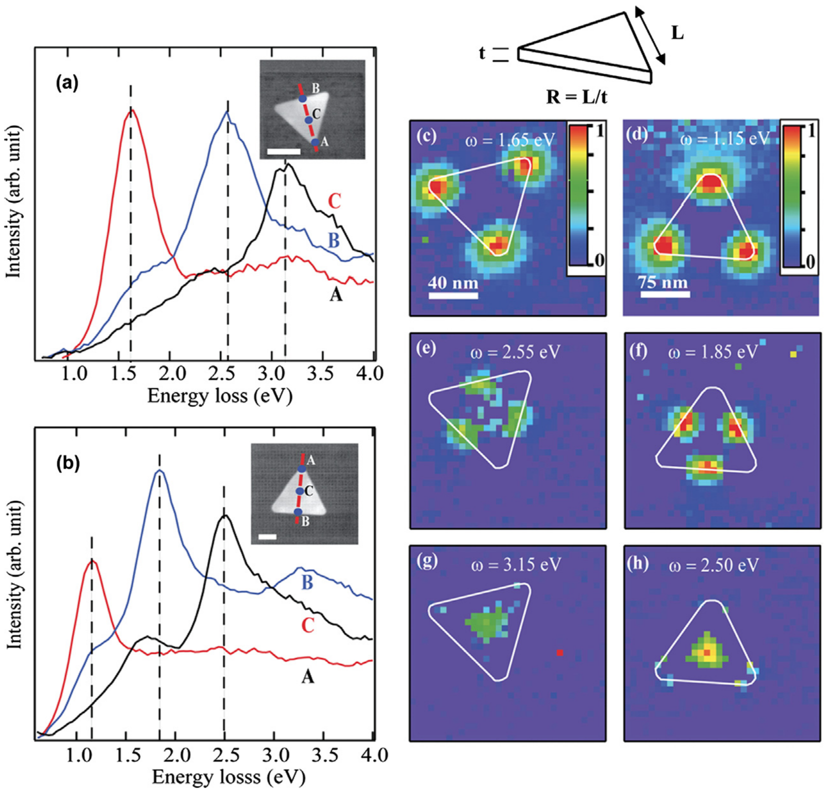

Fig. 1. (Colour online.) Size-dependent mapping of plasmons in silver nanoprisms. EELS spectra acquired at a corner (A), the middle point of an edge (B) and the centre (C) of (a) a 97-nm edge-long (thickness 4 nm) (b) and a 176-nm edge-long (thickness 6 nm) nanoprisms, respectively.
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Fig. 2. (Colour online.) The academic and industrial partners involved in ESTEEM 2.

cases at the atomic scale, in order to provide a better suite of methods that can be applied by academic and industrial users. This JRA combines holography and tomography developments including design and application of new tomography holders, acquisition schemes and reconstruction algorithms. The fifth JRA is slightly different from the previous ones and is devoted to "Time-resolved transmission electron microscopy". It includes the design and development of new fast electron detectors to provide dynamical studies at the millisecond time resolution and of a new hybrid instrument combining a femtosecond laser source and a transmission electron microscope based on a field emission source.

As for ESTEEM(1), besides the TA and JRA activities, ESTEEM2 aims at promoting TEM over a scientific community even larger through the organisation of TEM schools and workshops, the creation of fully open data bases with free TEM software, recipes for dedicated sample preparation procedures for "special" objects (hybrids, soft materials…), etc.

ESTEEM(1) has been very successful both in term of advanced TEM developments achieved within this program and in the number of external users who came through TA to perform advanced TEM experiences with the consortium equipment. The academic and industrial communities have largely benefited from this European initiative for the development of their own projects as well as the European "TEM community" which get the opportunity to tighten their connections and collaborative projects and then pushed forward TEM into new innovative topics. These successes drove the EU to support the continuation of ESTEEM(1) with the main goal of giving to Europe the most advanced TEM tools to help the scientific and industrial communities to push forward the capabilities of Europe in science and (nano)technology.

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