PROJECT FINAL REPORT

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Executive summary

Nanostructured electromagnetic materials are rapidly maturing and become increasingly employed for design of the electronic and optical components, integrated circuits and functional devices. For such applications, the **electromagnetic parameters** of materials are of the primary importance. However, the measurements and extraction of the electric parameters of nanostructured materials poses enormous conceptual challenges, especially for new materials with exotic electromagnetic properties. At this stage, neither the commonly-accepted test procedures nor a unified set of electromagnetic parameters have been defined and adopted for certification of nanostructured electromagnetic materials in different frequency ranges (microwave, THz, optical).

The **main project objective** was to consolidate efforts and bring coordination in the European work towards the development, testing, and dissemination of methods and tools for electromagnetic characterisation and metrology of nanostructured composite materials. The respective characterization techniques should be a) developed; b) tested; c) compared; d) catalogued and e) disseminated to the standardisation bodies, industries and SMEs. The project was aimed at initiating and coordinating cohesive actions in all the aforementioned directions.

The main theoretical results of the project work (analysis of the current status and recommendations for characterization procedures and for future research) have been structured as a series of documents available at the project web site and disseminated via conferences (including special sessions organized by the consortium) and overview publications. Furthermore, the results have been collated in the coherent tutorial-level text, prefaced by a non-specialist level introduction into the electromagnetic properties of nanostructured materials and their effective parameters.

The content of the project web site (**http://econam.metamorphose-vi.org**) is one of the main achievements, as it accumulates and presents all the project results to all target audiences, rising their awareness on the critical points in the area. The site has sectioning “for beginners”, “for specialists”, and “for industrialists”, and plethora of materials, especially of tutorial and introductory nature. The new web site layout helps the users with various backgrounds to find the materials which are directly targeted to them. In addition, the project web site has a separate menu

which provides a step-by-step guide to the user, bringing the relevant materials in the logical and easy-to-use way. Educational activities of the CSA were organized in form of tutorial lectures and in form of short (up to one week) focused doctoral schools. Especially the school organized during the last year of the project was a success, since that was a unique event where the students had a chance to actually make characterization measurements as well as interpret their results.

Overall, analysing the most recent literature and conference presentations in the field of electromagnetic characterization of complex materials, we can conclude that **the project has reached its main objective** to “consolidate efforts and bring coordination in the European work towards development, testing, and dissemination of methods and tools for electromagnetic characterisation and metrology of nanostructured composite materials” and has certainly made impact to (i) Capacity building in Europe in nanometrology; (ii) improved reliability of measurement and analysis at the nano-level; (iv) support to research and regulation, as was stipulated by the NMP call on CSA on material characterization.

The **project work has been praised by a number of users** (SMEs and FP7 NMP projects, in particular) via the feedback posted on the project web site.

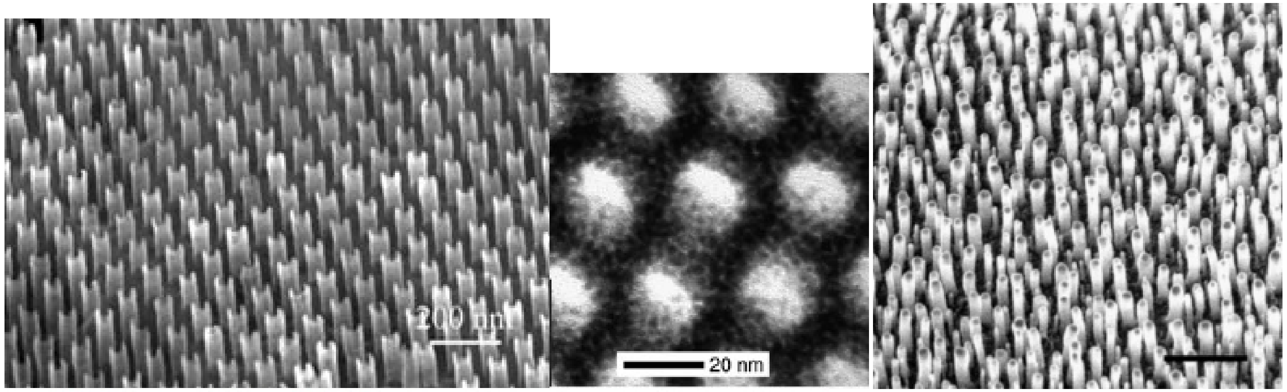
Summary description of project context and objectives

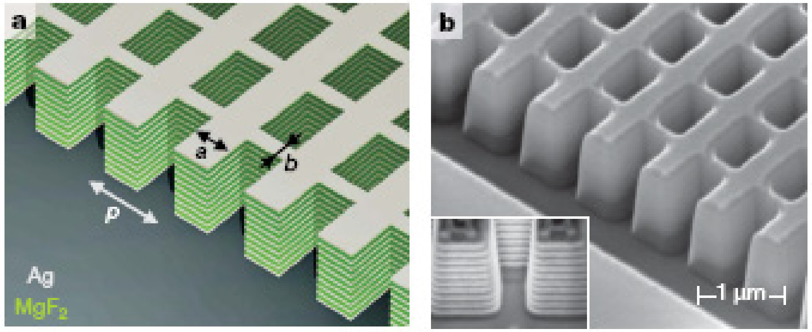
Nanostructured electromagnetic materials are rapidly maturing and become increasingly employed for design of the electronic and optical components, integrated circuits and functional devices. A broad class of applications is based upon the specialised electromagnetic materials that provide the necessary functionality for electronic devices and constitute the physical layer of the technologies dealing with electromagnetic signals. For such applications, the material **electromagnetic parameters** (permittivity, permeability, chirality parameter, grid impedance,…) are of the primary significance. Characterisation and metrology of the engineered nanostructured electromagnetic media have become the critical aspects of their development and utilisation in practical applications. The main novel characterisation approaches are focused on intrinsically interrelated developments and harmonisation of the material phenomenological models, standardisation of characteristic parameters and measurement techniques for evaluating the specified parameters.

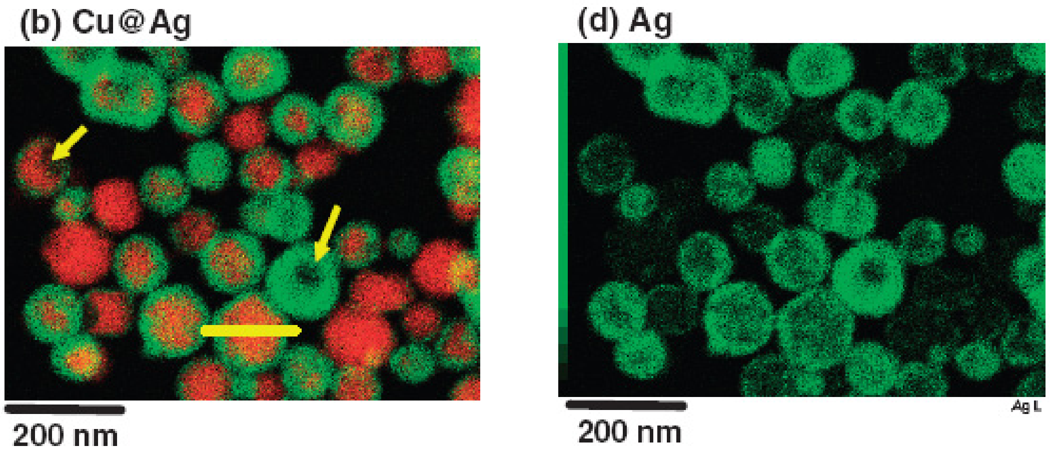
Usually the basic properties of conventional dielectrics and magnetic materials are described by permittivity and permeability. There are no means for the direct measurement of the electromagnetic parameters, which are dependent on the model used for their extraction. The approaches to measurements of even these fundamental electromagnetic characteristics of materials vary dramatically for electromagnetic waves of different frequencies, e.g. radio waves and light, and require specialised measurement techniques. These difficulties are dramatically escalated in electromagnetic characterisation and metrology of nanostructured materials. At the present stage of research, development and exploitation of nanoparticles and nanocomposites, they are characterised only in terms of geometrical parameters (particle size, lattice period, etc.) and sometimes by chemical reactivity. **Electromagnetic characterisation of nanocomposite materials** and understanding the structure-electromagnetic properties relationship, especially in the optical range, **is a novel field of electromagnetic science**. A comprehensive phenomenological description, with definitions and a consistent metrology of the constitutive electromagnetic parameters of nanocomposites, are paramount for their applications. Examples of nanocomposites include photonic crystals and optical metamaterials (arrays of plasmonic nanowires, carbon nanotubes, artificial optical magnetics, super- and hyper-lenses). The present lack of established, adequately tested, and widely adopted characterisation methods, tools and test procedures suitable for unambiguous description of electromagnetic properties of nanocomposites hinders further development and use of novel materials in practical applications, especially in optical devices and sensors.

The **main challenges in electromagnetic characterisation** and metrology of nanostructured materials include the mesoscopic scale and regime of operation. In the majority of practically realizable nanostructures the nanoparticle feature sizes and the characteristic lattice constants are smaller than the operational wavelength of light but comparable with it. For example, a device can operate at the wavelength of 500-600 nm, the structural periodicity is 50-100 nm, and the particle sizes are of the order of 30-70 nm. Such structures can still be described in terms of effective parameters (permittivity and permeability) of an equivalent homogeneous medium. However, the conventional models based on quasi-static homogenisation procedures normally applied at the atomic level are not applicable here, and the resulting effective phenomenological parameters (like permittivity and permeability) have different physical meaning as compared with conventional materials.

The following picture illustrates some typical geometries of nanostructures which have been of main interest of this CSA (pictures taken from journal publications).







The main problems which were addressed by the CSA project:

- The complex geometry and plasmonic resonances of individual nano-inclusions, which form a composite material, cause material resonances even for electrically dense composites. The standard description using the models of a homogenised effective medium is inapplicable near these resonant frequencies.
- Realisable nanocomposite films usually contain only a few layers of nanoparticles (often just one layer). The description of layer properties in terms of bulk material parameters (permittivity and permeability) has limited validity.
- The lack of consistent phenomenological models and established system of the characteristic parameters of nanostructured materials inhibit the development of coherent measurement methodologies and material metrology.

In the present situation, when approaches to electromagnetic characterisation of nanocomposites are only at the incipient stage, researchers either avoid the use of the conventional material parameters for such structures or extend the existing standard definitions beyond the limit of their applicability thereby sometimes violating the basic physical principles of causality, passivity and other fundamental laws. Due to the very nature of the nanostructured materials, the effective electromagnetic parameters have limited application range, but these constraints are yet not well defined and even the existing knowledge is not properly disseminated. As a result, the material users in industries and SMEs often cannot adequately exploit the measured parameters of nanostructures for design of new devices. It is obvious that in this situation, considerable coordination efforts are needed for timely solution of the current problems in electromagnetic characterization of nanomaterials, and that was the main goal of this CSA.

The **main project objective** was to consolidate efforts and bring coordination in the European work towards development, testing, and dissemination of methods and tools for electromagnetic characterisation and metrology of nanostructured composite materials. The necessary characterization techniques should be a) developed; b) tested; c) compared; d) catalogued and e) disseminated to the standardisation bodies, industries and SMEs. The project was aimed at initiating and coordinating cohesive actions in all the aforementioned directions.

The **main expected impact** is in the development and dissemination of novel techniques for electromagnetic characterization of nanostructured materials. This will complement the known techniques for characterization in terms of particle and reactivity by developing unified approaches to characterization in terms of permittivity, permeability, chirality parameter, surface impedance, grid impedance and similar relevant parameters.

A description of the main CSA results

In order to achieve the project goals, this Coordination Support Action organized the following main activities.

A representative group of the leading scientists working in this area of research and development was convened and became the core partners of this CSA. They established **Expert Consultative Groups**. Because the project funding could be used only to support the work of the project partners, the active core of the expert consultative groups was formed by the project beneficiaries. However, the project was able to attract a volunteer representative of the National Physical Laboratory (UK) as a member of one of the groups. The group members were responsible for organization of all the activities as well as dissemination and reporting. Active participation of a wide scientific and technical community was ensured by active discussions during the **special conference sessions organized by CSA** at the relevant major international conferences and by wide dissemination and educational activities of the CSA.

The Expert Consultative Groups

- shared their own knowledge in this area, searched and gathered information from all available sources,
- systemized the information, discussed and evaluated the current trends and achievements in this field,
- established a forum and coordinated efforts in the development and harmonisation of the methodologies for modelling, characterisation and parameter specifications of nanostructured materials,
- coordinated activities in the development of the measurement methodologies and test procedures,
- prepared materials for dissemination and knowledge transfer.

The work of Expert Groups and dissemination activities were supported by the dedicated web pages of the project and also by the dedicated web facilities available at the METAMORPHOSE Virtual Institute web portal (http://www.metamorphose-vi.org/). New tools such as a specialized database on characterization facilities were created.

Web-based video lectures and courses for dissemination of knowledge were created and made publicly available at the project web site.

One of the main project dissemination activities resulted in the brochure *"Nanostructured Metamaterials"*. It is available for downloading from the EU EC website for free (http://ec.europa.eu/research/industrial_technologies/pdf/brochure-metamaterials_en.pdf) or can be ordered from the EU bookshop website.

Special attention was paid to the **educational activities** for students, PhD students, researchers and engineers, especially from SMEs. This was done mainly by means of international doctoral-level schools on the subject of the CSA and via educational materials targeted to specific audiences and available at the project web site.

The project were made available in form of web resources of various types and posted to the project web site as soon as they were ready. Each deliverable was posted on the web site as a separate file but also as a part of the **cohesive tutorial arranged as a set of interrelated web pages with a guiding menu**. This way the web site was built as a dynamically growing and re-structuring tool, under development from the start to the end of the active project life.

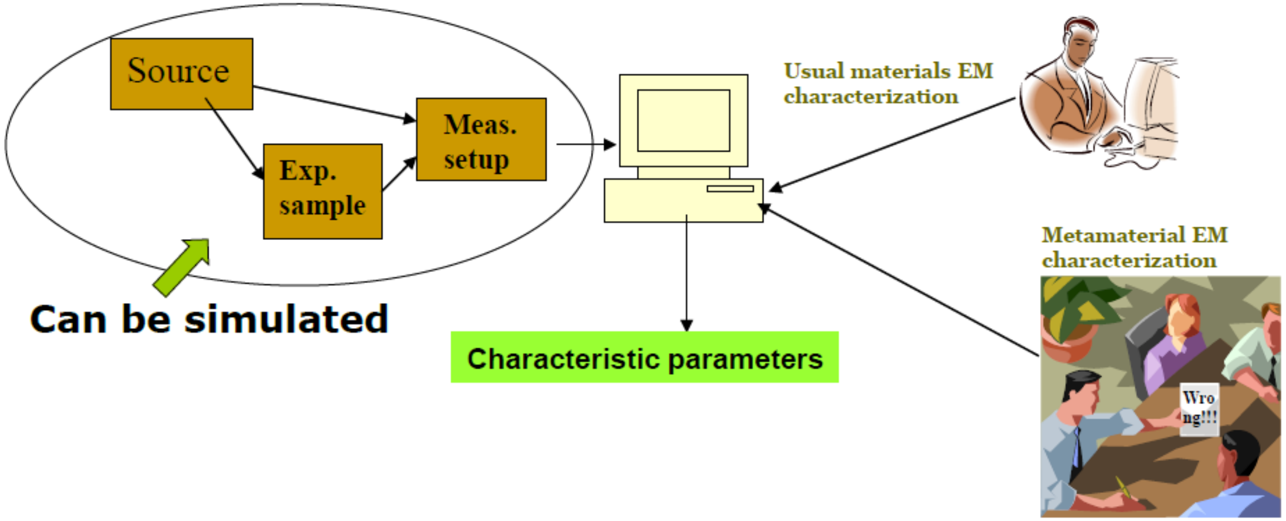
The CSA activities were organized in workpackages, and in the following we present the main results and achievements for each CSA workpackage.

Workpackage 1: Expert Consultative Group on the theory and modelling of electromagnetic characterization of nanostructured materials (workpackage leader Prof. C.R. Simovski, Aalto University, Finland)

The objective of this workpackage was to collect, digest and disseminate the state-of-the-art information and identify future research directions in the theoretical and modelling aspects of the electromagnetic characterization of nanostructured composite materials in the optical frequency range using analytical and numerical methods.

The work was coordinated and lead by the members of the Expert Consultative Group (participants of the CSA consortium), but the results should be credited to the wide scientific community owing to their active participation in discussions at the conference special sessions organized by ECONAM CSA and via informal exchanges with the ECONAM partners.

The following picture illustrates the electromagnetic characterization roadmap which goes from measurement of electromagnetic response of the sample (such as reflection coefficient) via some material parameter extraction procedure to the physical interpretation of the obtained results.



The main problem which the CSA addressed is that in the majority of situations for complex nanostructures, the conventional methods of retrieval of the characteristic parameters (like the permittivity and permeability) lead to non-physical and, thus, practically useless results.

At the first stage of the project, this Expert Group made an analysis of the scientific and technical literature and found that indeed there is a severe lack of applicable characterization techniques for nanostructures and for nanostructured metamaterials in particular. The detailed literature overviews with expert analysis of advantages and drawbacks of different methods were produced and the stringent restrictions of the known methods were explained.

Next, the project produced surveys of the most common mistakes and pitfalls in the electromagnetic characterization of nanostructured composite materials when the conventional and known methods are used.

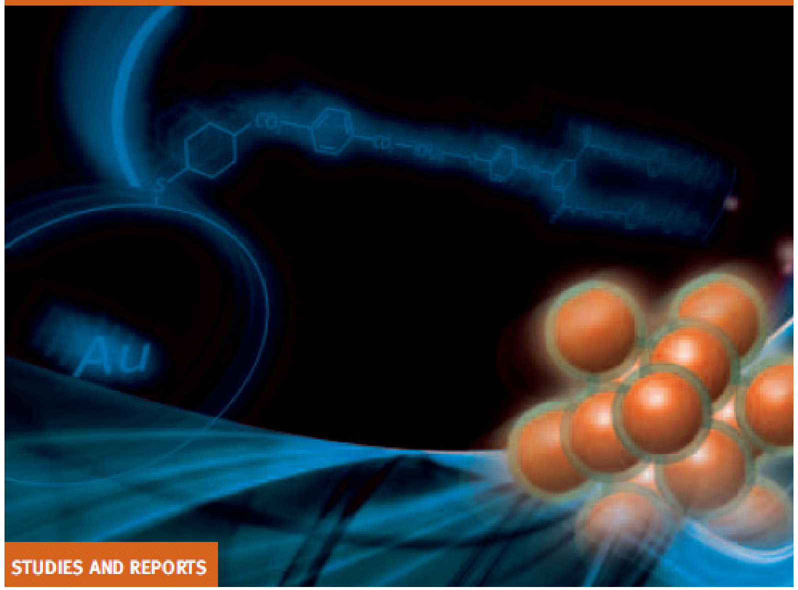
The next step was the consolidation of the collected information towards creating physically sound and practically applicable characterization methods and identifying the applicability limits for the classical methods. To this end, the project developed a classification of nanostructured materials including metamaterials and general approaches to their electromagnetic characterization. The most promising (physically meaningful and practical) methods which are currently under development were identified and this knowledge was disseminated and promoted in order to encourage their development and use.

The aforementioned activities were targeted towards experts in the electromagnetic properties of complex materials and especially in electromagnetic characterization. In addition, a range of activities was organized in order to reach the wider scientific and technical community, especially experts in nanofabrication. Links between electromagnetic, structural and chemical characterizations were explained in a dedicated deliverable. An educational brochure *"Nanostructured Metamaterials"* contains chapters on the theoretical aspects of electromagnetic characterization as well as an overview introduction to the electromagnetic properties of materials in general. These chapters are accessible to a broad community of material scientists and experts in nanofabrication as well as to non-specialists in this field.

EUROPEAN COMMISSION / European Research Area / Industrial research

Nanostructured Metamaterials

Exchange between experts in electromagnetics and material science



STUDIES AND REPORTS

Furthermore, educational and overview lectures were developed and presented to participants of new NMP projects on fabrication on metamaterial structures in a special workshop organized by ECONAM in Brussels.

The workpackage work results are summarized in the consolidated public overview available in form of a separate document (deliverable D1.1.6) and as a part of a tutorial overview of approaches to electromagnetic characterization of nanostructured materials (both are available at the project web site). The final review and recommendation documents contain a discussion of the suggested road map for future research and development.

The workpackage results were disseminated via the project web site, presentations and discussions at scientific conferences as well as via review presentations and publication of review papers (see more details in the dissemination section of this report).

Workpackage 2: Consultation and support of the research community and third parties on the measurement techniques and standards in measurements (workpackage leader: Prof. Alex Schuchinsky, Queens University of Belfast, UK)

The work of this workpackage was organized and lead by the Expert Consultative Group on measurement techniques. The group has the following tasks:

- Prepare detailed overviews of the state-of-the-art and most promising measurement techniques employed for retrieval of the phenomenological electromagnetic parameters of nanostructured materials, make analysis and identify future research directions,
- Develop recommendations for electromagnetic researchers and material scientists for choosing the best measurement technique for electromagnetic characterization consistent with the definitions of the phenomenological electromagnetic parameters. Produce, gather and systemise information for regular updates of the website content for SMEs and industries,
- Provide suggestions on how to characterise electromagnetic properties of the materials under development in the manufacturing projects (FP7 NMP).

This has been a challenging set of tasks. Indeed, optical metamaterials, because of their typically limited area and number of functional layers, are more easily understood as finite structures with interfaces that define their optical behaviour. This definition is in contrast to a conventional material in which their bulk properties define their optical properties. The retrieved 'material' parameters are a subject of interpretation unless the samples have sufficient extent in the direction of wave propagation to neglect the interface effects. Also the phase information is more difficult to obtain. It requires either more sophisticated measuring tools, such as time domain or interference methods, or alternatively, more complex structures, e.g. phase masks made with the metamaterial. As a result, there is no simple and universally applicable measurement technique and test equipment. Moreover, the method for extraction of effective electromagnetic parameters from measured results should be carefully chosen for every particular sample, and the results must be thoroughly examined for their consistency with the fundamental physical principles.

In the first task, the detailed overview of the available experimental techniques has been developed step-by-step. During the first project year, the first version was created, which was then broadly discussed at the special conference sessions organized by the project as well as via individual discussions with experts in the field (including non-European experts). This material contributed in part to the popular brochure *"Nanostuctured Metamaterials"*, published by the European Commission. The overview document was updated every six months, and finally, a consolidated overview of the state-of-the-art and most promising measurement techniques employed for retrieval of the phenomenological electromagnetic parameters of nanostructured materials has been compiled at the end of the project. This final document has been disseminated via the project web site as a separate document, as a part of the logically structured tutorial, and finally it contributed to the extensive tutorial overview of the approaches to electromagnetic characterization of nanostructured materials, which is one of the major project outputs.

Similarly to the work done by the Expert Group of workpackage 1, the results should be credited not only to the members of the Expert Group, but also to a broad scientific community actively participated in discussions at the conference special sessions organized by ECONAM CSA and via informal research exchange with the ECONAM partners.

Work on the second task was mainly targeted at the development and structuring of the informative and tutorial materials for the project web site. The result is a web site where scientists and engineers (both experts in electromagnetic characterization of materials and users of measurement equipment) as well as industrialists can find credible information and recommendations presented in a structured and targeted form. The web tools include informative databases of appropriate equipment as well as information about availability of the necessary equipment in European institutions, as well as technical recommendations and scientific explanations of parameter extraction procedures.

Work on the last task (Provide suggestions on how to characterise electromagnetic properties of the materials under development in the manufacturing projects (FP7 NMP)) resulted in the development of a **Road map for experimental characterization of metamaterials.** This tool (available on the project web site) provides a step-by-step guidance on how to determine experimentally what kind of structure is tested and, if this is indeed a new material, how to assess the electromagnetic properties of composite material samples. The following picture illustrates the layout of the road map (only the first step is shown).

Experimental steps	**Short explanations**
Step 1. Is the sample a piece of an effectively homogeneous material or a (complicated mesoscopic) structure?	
Measurement of diffuse scattering from the sample shaped as a planar layer. The sample is illuminated by a wave beam with nearly flat phase front incident at a certain angle. The beam width is small enough so that the edges of the layer under characterization are not illuminated. This incident wave beam models the plane wave incident on the infinitely extended layer. Amplitude of fields, reflected, transmitted and scattered at all directions, is measured. Measurements at a given frequency can be repeated for several incidence angles. These measurements can be done at several frequencies.	The aim is to determine the level of diffusion scattering for frequencies and angles of incidence which are of our interest. If we observe that (for a given frequency and incidence angle) nearly all reflected energy propagates in the specular direction, according to the usual reflection law, then we deal with an effectively homogeneous sample (for this frequency ω and this incidence angle α). If we observe side lobes or high level of diffusion scattering, it means that the sample is not an effectively homogeneous material, and we deal with a more complex system. This can be a diffraction grating or a photonic crystal or whatever.

This road map has two versions - one is for non-specialists and the other for experts in the field. In the latter version, additional details are given as well as recommendations are provided for future work on the development of experimental techniques. The road map has accumulated the results of the work performed in this project and, according to the schedule, was finalized at the end of the project. These results have been posted on the project web site and will be promoted by the project participants beyond the project lifetime. Naturally, adoption of the novel advanced characterization techniques will require extensive discussions in the wide scientific community and it will involve a number of iterations before becoming universally accepted.

<u>Workpackage 3: Access to measurement facilities, computational tools and data banks</u> (workpackage leader Dr. Vladimir Podlozny, Metamorphose Virtual Institute, Belgium)

This work package organized access for SME and other interested organisations in Europe to the existing measurement, computational and data resources at the public laboratories of the project beneficiaries. Also it facilitated access to other European EM NSM characterization centres via information management activities and promotional actions.

The organized access (not only to the facilities of the project beneficiaries but also to other leading European organizations) was provided via a number of tools developed and posted on the project web site. The workpackage has collected information about the available facilities and made it accessible in form of well organized and searchable databases published on the web site.

The following laboratories contributed to the facilities database:

Institut fur Photonik und Quantenelektronik, Karlsruhe University, Karlsruhe, Germany
Laboratory of Physical Chemistry, Swiss Federal Institute of Technology Zurich, Switzerland
Institute for Atomic and Molecular Physics, Amsterdam, Netherlands
Nanophotonic, Institut of Physics, Faculty of Mathematics and Science, Technical University of Ilmenau, Ilmenau, Germany
Nanobiotechnology-Group, Gutenberg Universität, Mainz, Germany
Physikalisches Institut, Physikzentrum, RWTH, Aachen, Germany
Physikalisches Institut, Universitaet Stuttgart, Stuttgart, Germany
Center for Innovation Competence, Institute of Applied Physics, Friedrich Schiller University Jena, Jena, Germany
The Institute for Nanotechnology, University of Karlsruhe, Karlsruhe, Deutschland
Optoelectronics Research Centre, University of Southampton, Southampton, UK
Center for Solid State Physics and New Materials, Belgrade, Serbia
Center for Surface and Nanoanalytics, Linz, Austria

Sentech Instruments GmbH, Berlin, Germany
Institute of Applied Physics Friedrich-Schiller-Universität Jena, Jena, Germany
Institute for Analytical Sciences, Berlin, Germany

The laboratory profiles contain also information about access rules currently adopted at each site.

The appropriate facility or computational tool can be found in accordance with the type of measurement or the type of equipment or by the type of material under study. Each facility is described in detail, including the contact information of the local person responsible for organization of access by external users.

The access tools developed by the ECONAM project were promoted through web-posted news, via review presentations at conferences and review papers describing ECONAM project activities.

Workpackage 4: Dissemination, education, and training (workpackage leader Prof. Filiberto Bilotti, University Roma Tre, Italy)

Special efforts and measures are needed to deliver new knowledge, new measurement techniques, and approaches to extraction of effective material parameters. **The main current problem** in the area of research and development that we addressed by this CSA is that **there are no well developed and commonly accepted characterization techniques**.

The recent achievements in electrodynamics of nanocomposites have shown that it is impossible to apply the existing concepts of electromagnetic characterization of materials to nanocomposites. In the situation when this new knowledge is not properly disseminated, it may lead to negative unpredictable consequences. For example, the old concepts are used as the theoretical foundation of software used in the commercial measuring devices (ellipsometers, etc.). This means that in majority of situations the measured parameters cannot be utilized in device design because the physical meaning of the parameters is not clear or even wrongly defined. It is obvious that there is a pressing need to disseminate the latest knowledge in this field and promote creation of commonly accepted characterization techniques. Furthermore, the users of new nanostructured materials should be educated in the area of electromagnetic characterization, so that they can use the measured parameters to predict material performance in a particular device.

The dissemination activities are targeted towards: a) researchers in electromagnetic and material science; b) industries and SMEs; c) general public. Next we present the workpackage results in each of its tasks.

The first task was to **organize European School Events on NSM characterization of advanced electromagnetic materials** each year. This work was lead by the Metamorphose Virtual Institute and completed successfully. School on "Fabrication and optical properties of nanostructured metamaterials" was organized in conjunction with the "8th International Conference on Electrical Transport and Optical properties of Inhomogeneous Media" (ETOPIM8) on Crete, Greece, June 12-13, 2009. The illustration shows the home page of that school event.

EUPROMETA – EUROPEAN DOCTORAL PROGRAMMES ON METAMATERIALS

School on "Fabrication and optical properties of nanostructured metamaterials"

Distributed European Doctoral School on Metamaterials

School on "*Fabrication and optical properties of nanostructured metamaterials*"

In conjunction with the "8th International Conference on Electrical Transport and Optical properties of Inhomogeneous Media" (ETOPIM8)

June 12 (afternoon) & 13, 2009, Aquilla Rithymna Beach Hotel, Rethymnon, Crete, Greece

School organizers:

Maria Kafesaki, Costas Soukoulis, and Sergei Tretyakov

The current edition of the Metamaterials School is devoted to the optical properties and the realization possibilities of nanostructured metamaterials, targeting operation in the near IR and optical regime. The recent and foreseen developments in terms of fabrication, optical characterization, and novel optical phenomena related with nanostructured metamaterials will be reviewed and analyzed by experts of the field.

The ECONAM project contributed to the one-week international school on Fundamentals of Metamaterials Electromagnetics (November 16-20, 2009, Levi, Finland), with three (out of four) lecturers provided by the ECONAM project partners.

In the last year of the ECONAM project activities, the project organized a week-long school on experimental electromagnetic characterization of complex materials and metamaterials. Below is a picture showing the home web page of this event.

17th school

17th European Doctoral School on Metamaterials
on
Experimental Characterization of Electromagnetic Metamaterials
Dates: December 13-17, 2010
Location: Foundation for Research and Technology Hellas (FORTH), Crete, Greece
Organizers:
FORTH – Institute of Electronic Structure and Laser (IESL)
Metamorphose Virtual Institute

Instructions on how to arrive to FORTH buildings (school venue)

This school is organized in the framework of the Metamorphose European Doctoral Programmes on Metamaterials (http://school.metamorphose-eu.org). Also, it is part of the activities of the FP7 Coordinating Action ECONAM (Electromagnetic Characterization of Nanostructured Materials - http://econam.metamorphose-vi.org/)

The current edition of the Metamaterials School is devoted to experimental electromagnetic characterization of metamaterials and to the available characterization techniques. Various available characterization approaches will be discussed in detail, along with their regimes of validity, and various experimental characterization techniques will be presented. These characterization techniques will concern metamaterials operating from microwaves all the way to the optical regime. The presentations will be accompanied by laboratory courses where the students will have the opportunity to familiarize themselves with the details of each experimental procedure.

Characterization techniques that will be discussed include microwave transmission and reflection measurements (both amplitude and phase), THz timed domain spectroscopy, Fourier transformed infrared spectroscopy, optical spectroscopy, ellipsometry, etc. In particular, we plan laboratory exercises on characterization of planar composite slabs, with the focus on double-negative composites, measurements of surface impedance of high-impedance surfaces, measurements of polarizabilities of artificial magnetic inclusions, and other experiments.

This has been quite a unique school event, as it included the actual experimental measurements made by the students as well as complete post-processing of the results and discussion of the validity and the physical meaning of the results.

All the school events have got most positive feedback from the participants.

The second task was to prepare **online and offline web-based electronic courses on NSM characterization**. This work resulted in an extensive video tutorial lecture available for download from the project web site, as well as in an educational section on the web site. In addition, all the lectures presented at the doctoral school events have been recorded as video files or as a set of slides and all these materials have been posted on the doctoral school web site.

The next task was to organize **special sessions on electromagnetic characterization techniques** and existing European facilities for NSM at the METAMATERIALS Congress and other conferences.

The main efforts of this CSA were on coordination and support to the European work towards development, testing, and dissemination of methods and tools for electromagnetic characterisation and metrology of nanostructured composite materials (metamaterials). Based on this, for discussions of problems of electromagnetic characterization of composite materials we have chosen the main forums where experts in this area of nanoscience and material science meet: Metamaterials 2008 (Pamplona) and 2009 (London), Meta'2010 (Cairo), and others. The dissemination efforts were directed to a wider audience including other areas of nanoscience and material science, as well as potential applications of novel electromagnetic properties of nanostructured metamaterials. These conferences include Material Research Society (MRS) Meeting, Forum on New Materials, Electromagnetics in Advance Applications, and others.

Below we provide some details about the most prominent events.

Metamaterials Congress (http://congress2011.metamorphose-vi.org/), organized by the Metamorphose Virtual Institute (one of the beneficiaries of the ECONAM project) has been one of the main dissemination engines for ECONAM.

A panel session organised by the ECONAM project has been convened at the **Second Congress on Artificial Electromagnetic Materials for Microwaves and Optics, Metamaterials 2008** held in Pamplona, Spain on 21-26 September 2008. The session entitled "Theoretical Issues and Practical Aspects of Metamaterial Characterisation" has been organised by Prof. A. Schuchinsky (partner of ECONAM) and Prof. R. Mittra, Pennsylvania State University, USA. The panellists were
Prof. Sergei Tretyakov, Helsinki University of Technology, Finland (ECONAM partner),

Prof. Allan Boardman, University of Salford, UK,
Prof. Ricardo Marques, University of Seville, Spain,
Prof. Stefan Linden, Karlsruhe University, Germany (ECONAM partner),
Prof. Yang Hao, Queen Mary University of London, UK,
Prof. Raj Mittra, Pennsylvania State University, USA,
Prof. Alex Schuchinsky, Queen's University Belfast, UK (ECONAM partner).
The panel session attended by more than 100 participants of the Congress comprised brief presentations by the panellist followed by the extensive interactive discussion involved both the panellists and audience. The session materials are available at the ECONAM website.

A special session entitled "Progress of the ECONAM project" was organized at the **Third International Congress on Advanced Electromagnetic Materials in Microwaves and Optics – Metamaterials 2009**, held in London, UK on 30 August – 04 September 2009. In the ECONAM special session there was massive participation of NMP audience, especially of experts in the particular field of this CSA (electromagnetic characterizations of nanostructured materials).

Here is the list of presented papers:
Henrik Wallén, Henrik Kettunen, Ari Sihvola, Helsinki University of Technology (AALTO), Finland, Applicability of classical mixing rules: from positive to negative parameters
Costas Soukoulis, J. Zhou, M. Kafesaki, Th. Koschny, Foundation for Research and Technology Hellas (FORTH), Greece, Weakly and strongly coupled optical metamaterials
Chris Fietz, Dmitriy Korobkin, Burton Neuner, Department of Physics, Chihui Wu, Gennady Shvets, Department of Physics, The University of Texas at Austin, USA, Characterization of plasmonic metamaterials using effective parameters
Constantin Simovski, Helsinki University of Technology (AALTO), Finland, On the locality of Drude transition layers for metamaterials
Alexey Vinogradov, Alexander Merzlikin, ITAE, Russia; Said Zouhdi, Laboratoire de Génie Electrique de Paris LGEP-Supélec, France, On non-Maxwellian boundary conditions for metamaterial interface

As is seen from this list, participation of experts from outside the ECONAM participants was ensured, and it was the key for the meeting success.

In 2010, ECONAM organized a special ECONAM session at conference META 2010 (Cairo). This event was very well attended by experts in nanoscience and material science, working on electromagnetic properties of nanostuctured materials. At this session, intermediate results of workpackages 1 and 2 have been disseminated, and, most important, the members of ECONAM expert consultative groups met each other and other distinguished experts in the fields, which resulted in decisive contributions to the analysis and recommendations presented in updates to a number of deliverables.

The session was introduced by a keynote presentation by A. Vinogradov (ECONAM partner ITAE) entitled "Homogenization of metamaterials: bulk properties and boundary conditions". In this talk the pitfalls of different approaches of introduction of effective constitutive parameters were considered. *Today we encounter a situation that remembers one in the beginning of the twenty century. It was the time of a crisis of classical mechanics, which finished with creation of relativistic theory and quantum mechanics. Now we go through the crisis of classical electrodynamics of condensed matter developed by Maxwell, Heaviside and Lorentz. Indeed, as in the beginning of twenty century, we observe an increase of experimental results that can hardly be explained with the existent theories.*

Here is the list of the other papers presented at the session:
Yu. E. Lozovik (ITAE), Electromagnetic characterization of graphene and graphene based nanostructures
A. G. Schuchinsky (QUB), A. Vallecchi, A.P. Shitvov and F. Capolino, Resonance transmittance in metamaterials made of stacked arrays of dogbone shaped conductor pairs
S. Larouche and D. R. Smith, Quantifying the nonlinear susceptibility of metamaterials
D. Mogilevtsev, F. A. Pinheiro, R. R. dos Santos, S. B. Cavalcanti and L. E. Oliveira, Anderson localization in disordered dispersive metamaterials
M. H. Belyamoun, A. Bossavit and S. Zouhdi, Frequency-dependent homogenization of split-ring arrays
R. Kotynski, T. Stefaniuk, A. Pastuszczak, Sub-wavelength diffraction-free imaging in low-loss metal-dielectric multilayers

The special sessions organized by ECONAM provided an important and timely review of the state-of-the-art in characterisation of artificial electromagnetic materials, which was later recorded in updates to ECONAM deliverables and on its web site tools. The papers have been presented by the experts in the field, who addressed the current issues on the definition and determination of the physical parameters suitable for the meaningful description of the metamaterial properties. The sessions represented also an important place where the latest results on the characterization of nanostructured materials have been discussed and where the experts in the field got together and compared the different approaches used.

Actually this activity was not only a part of work on dissemination – these special sessions were of key importance for the work of the Expert Consultative Groups (Workpackages 1 and 2). At these sessions the preliminary results of the expert group work were discussed within the wide international scientific community, and here the experts of the project collected information on the latest developments in the field of their expertise, which was then used to update and develop the analytical reviews and recommendation documents of the ECONAM project. As explained above, due to the FP7 financial rules it was not possible to involve more external experts into the project consultative groups directly, and these special sessions were successfully used as a tool to dramatically widen the scope of the project activities due to participation of experts not directly involved in the ECONAM project.

The task on writing the **monograph on electromagnetic characterization of nanostructured materials** has resulted in the tutorial overview of approaches to electromagnetic characterization of nanostructured materials. This extensive document (79 pages) has been formed and edited as the combined and structural output of the whole work of the Expert Consultative Groups during the whole project life. In addition, it contains an introductory chapter on basics of electromagnetic properties of materials. The book is accessible for non-specialists in the field, with appropriate references to original publications for the expert reader. Because this cumulative book was finalized (according to the work plan) at the end of the project, at this stage it could be disseminated only via the project web site. However, the ECONAM consortium is considering possible publication of this text as a book.

The last task of this workpackage was an **educational event for the new FP7 NMP projects on manufacturing of metamaterial structures**. The event was organized in December 2009 in Brussels, and was well attended by the beneficiaries of the respective NMP projects. The ECONAM project has organized the event and delivered a set of tutorial lectures not only on the topic of the CSA (electromagnetic characterization of nanostructured materials) but also tutorials on the basics of electromagnetic properties of materials and their description. Below we present the first slides of the three main lectures.

Basics of electromagnetic wave interaction with composite materials: polarization responses, dispersion, bianisotropics

Training Workshop for new FP7 projects on metamaterials
9–11 December 2009

TKK 1849 1908 2008

Ari Sihvola
Helsinki University of Technology
Finland

Measurement techniques for electromagnetic properties of nanostructured materials, available equipment, and service provision in Europe

(ECONAM FP7 project)

Lecturer: Constantin R. Simovski
Coauthor: Vladimir V. Podlozny

Dec. 9 2009

TKK

Metamaterial inclusion geometries and their electromagnetic properties

Sergei Tretyakov

FP7 NMP Metamaterials Workshop

December 2009

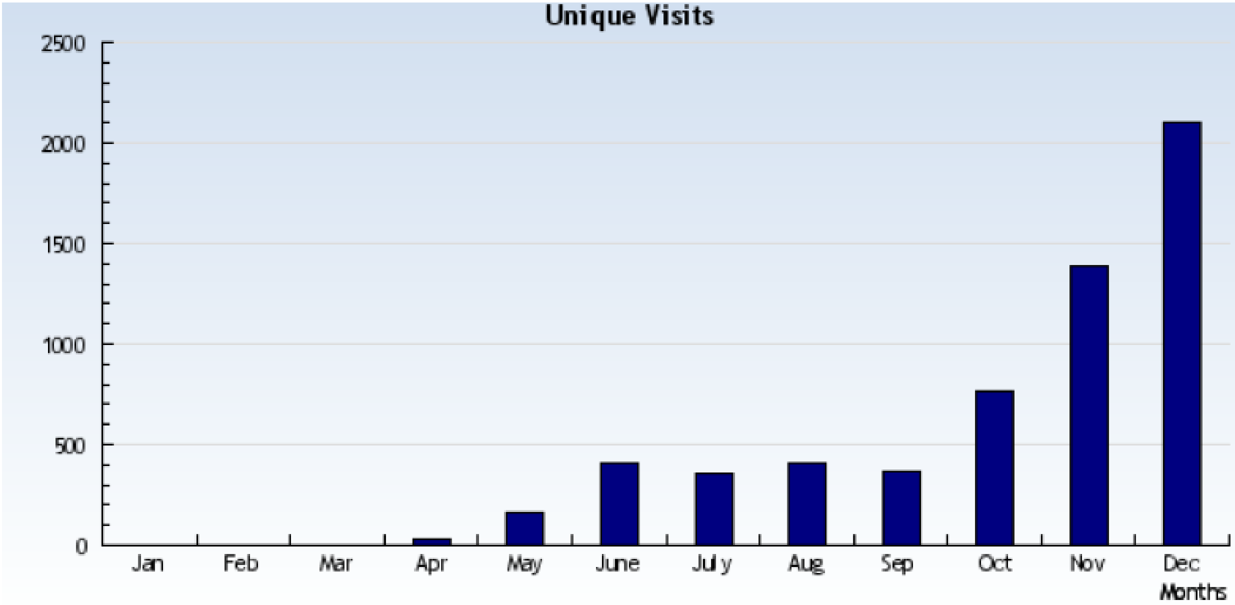
- Electromagnetic properties defined by chemical composition and (or?) geometry of the micro/nanostructure
- Artificial dielectrics and relevant inclusion geometries
- Artificial magnetics and relevant inclusion geometries
- Artificial chiral and bi-anisotropic media and related geometries

Metamorphose VI http:\\www.metamorphose-vi.org 1

Workpackage 5: Information and communication support for research and dissemination (workpackage leader Dr Vladimir Podlozhny, Metamorphose Virtual Institute, Belgium)

Starting from the project outset till its very last days the project web site http://econam.metamorphose-vi.org has been continuously evolving and developed as the main education and dissemination tool of the project. The web site structure has been constantly advanced. Each new deliverable or its update has been promptly posted on the web site and integrated in the overall structured and logical informational and educational skeleton. At the later stages, the web site received an additional menus “for beginners”, “for specialists” and “for industrialists”, with separate introductions and guidance pages targeted for each of these three categories. The menu “characterization” leads the reader step-by-step along the learning process, logically introducing the analytical and recommendation documents generated by the project.

The picture below illustrates the site popularity grows during the first project year.



Promotion of the project website took place at several scientific and technical meetings as well as on a number of commercial and public websites. The key persons participating in ECONAM promoted the site via their personal web sites. Links have been made also from participants' departments and laboratories web pages. The web site link was promoted via review presentations about ECONAM activities, both via the abstracts and proceedings publications and during talks. Promotional video was made and on Youtube: http://www.youtube.com/watch?v=RUar3D-2nTc.

The potential impact

The main impact of this CSA is in the development and dissemination of the novel techniques for electromagnetic characterization of nanostructured materials and preparing the basis for future standards in the field of nanomaterials characterisation in terms of the electromagnetic parameters. This will complement the known techniques for characterization in terms of particle and reactivity by developing unified approaches to characterization in terms of permittivity, permeability, chirality parameter, surface impedance, grid impedance and similar descriptions. These parameters will be able to characterize not only bulk materials, but also thin layers and interface behaviour. Acceptance of these new methods for electromagnetic characterization will have dramatic impact on nanotechnology applications especially in telecommunications, imaging, detection, and sensors.

The expected long-term impact will be adoption of common measurement tools for the electromagnetic characterization of nanostructured materials. Such unified measurement methods and tools and the parameter retrieval procedures will be very important for the European industry as this will allow them to use the standard characterization procedures for applications that involve nanostructured materials. This project has brought a new level of cohesiveness to the field of electromagnetic characterization of nanostructured materials. Coordination of the experimental measurement techniques and metrology standards used for characterization of nanostructured materials will result in reliable and reproducible material development efforts which are essential for future applications of nanostructured artificial electromagnetic materials. The benefits for industry and particularly SMEs will include access to the unique equipment and expertise that would ordinarily be too expensive in term of time and cost.

The development and broad adoption of the new characterization techniques is a long process, but even now we can observe that the impact of ECONAM project is quite visible and tangible. In the scientific and technical community there is much more awareness of difficulties and pitfalls in the conventional characterization techniques when one applies them to novel complex nanostructures. The analysis of the most recent literature shows that more and more papers attempt to fill the gaps of knowledge in this field and propose new advanced characterization methods, applicable to metamaterials. We are pleased to see the influence of our efforts on these growing international developments.

The ECONAM project web site is now acting as a virtual European facility for electromagnetic characterization of nanostructured composite materials, which offers comprehensive information on the well-established, tested, and widely disseminated measurement techniques and methodologies for the material parameter retrieval as well as the detailed knowledge on pitfalls, problematic issues, and novel approaches suitable for emerging complex nanostructured materials. The web site also provides a mechanism for sharing measurement facilities and providing quality metrology services for the industries and SMEs.

Project public website

The web site of the project (**http://econam.metamorphose-vi.org**) is one of the main project achievements (see also the results of workpackage 5), and it collects all the project results and presents them to all targeted audiences.

ECONAM

Search Google

For Beginners | For Specialists | For Industrialists

Metamaterials 2011

Characterization

- Motivation
- Glossary
- Classification
- Video
- Methods
- Roadmap
- Measurements
- Laboratories
- Overview
- Challenges
- Help

This project

- **Home**
- **About**
- **Activities**
- **Facilities**
- **Bibliography**
- **Events**
- **News**
- **Downloads**
- **Links**
- **Guestbook**

ECONAM - Electromagnetic Characterization of Nanostructured Materials

FP7 Coordinating and Support Action

Nanostructured electromagnetic materials are rapidly maturing and become increasingly employed for design of the electronic and optical components, integrated circuits and functional devices. They have ubiquitous applications ranging from the high speed computer chips to optical communications devices, high resolution imaging and biomedical sensors. A broad class of applications is based upon the specialised electromagnetic materials that provide the necessary functionality for electronic devices and constitute the physical layer of the technologies dealing with electromagnetic signals. For such applications, the electromagnetic parameters of materials are of the primary concern.

However, the measurements and extraction of the electromagnetic parameters (effective permittivity, permeability, chirality parameter) of nanostructured materials poses enormous challenges, especially at millimetre-wave, terahertz, and optical frequencies, where the samples are usually very thin and the structural period can be comparable with the wavelength. Furthermore, neither standard test procedures nor unified set of electromagnetic parameters have been defined for certification of nanostructured electromagnetic materials in different frequency ranges (microwave, THz, optical).

The **main project objective** is to consolidate efforts and bring coordination in the European work towards development, testing, and dissemination of methods and tools for electromagnetic characterisation and metrology of nanostructured composite materials. This should help researchers and engineers to characterize complex novel electromagnetic materials in a consistent and physically sound way and raise awareness of difficulties and related problems. The main novel characterisation approaches are focused on intrinsically interrelated developments and harmonisation of the material phenomenological models, standardisation of characteristic parameters and measurement techniques for evaluating the specified parameters.

The necessary characterization techniques should be a) developed; b) tested; c) compared; d) catalogued and e) disseminated to the research community, standardisation bodies, industries and SMEs. The project aims at initiating and coordinating the cohesive actions in all the aforementioned directions.

The project started on April 1, 2008, and its duration is 3 years.

One of the main project dissemination activities resulted in the brochure "**Nanostructured Metamaterials**". It is available for downloading from the EU EC website for free or you can order it from the EU bookshop website. Also other EU brochures related to nano-structured materials are available for download for free.

The overviews and sets of recommendations produced during the whole project duration are summarized in a **tutorial overview of approaches to electromagnetic characterization of nanostructured materials** (click on the title to download the pdf file).

The project finished its activities on March 31, 2011, and the content of this site is not anymore regularly updated.

This picture shows the home page of the project web site.

Conclusions

Based on the above-described CSA project results, the ECONAM consortium concludes that the project goals formulated in the project Description of Work have been successfully achieved.

The project received a number of commendations from the users of various background (via the web site "guest book"). Below are examples coming from small companies:

Jose Morales

> **Affiliation**: ANTERAL S.L.
> We are a SME company very interested in developing Metaterial based products. We think that projects as ECONAM really help to develop this technology and finally find applications in a real world.
>
> The contents of the web page are really useful and the information provided by the project is also very interesting for developing new nano materials.

Friday, 25 February 2011

Philip Johnston

> **Affiliation**: Trackwise
> Nano-structured metamaterials are an extremely interesting area of study and the potential for creation of innovative materials in Trackwise field of RF antennas is something that we are keen to be informed about.
>
> This is a very useful source of material; for obvious reasons I particulalry welcomed sections for beginners and industrialists!
>
> Keep up the good work.

Friday, 11 February 2011

The complete guest book is available at the project web site.

Use and dissemination of foreground

This project is a Coordination Support Action, which explicitly excluded any kind of research or development work. Thus, the project as such could not generate any scientific or commercially exploitable foreground results. Although the consortium members observe a growing number of scientific publications directly influenced by the ECONAM project activities, these publications have been created outside of the project framework and we do not list them here. Thus, in the following section we only include the tutorial and overview materials written and published by the ECONAM consortium.

Section A

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES

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	*Nanostructured Metamaterials, Exchange between experts in electromagnetics and materials science*	*Editor Anne F de Baas*	*Studies and Reports*	*No 43, March 1990*	*Luxembourg, European Union*	*Luxembourg*	*2010*		ISBN 978-92-79-07563-6	yes
2	*Electromagnetic Characterization of Metamaterials: Activities of the ECONAM Project*	*S. Tretyakov, C. Simovski, and A. Sihvola*	*AIP Conference Proceedings (vol. 1176), Proceedings of the 2nd International Workshop*	*Bad Honnef, Germany, October 28-30, 2009*			*2009*	*31-33*		No (copyright policy of the publisher)

			Theoretical and Computational Nanophotonics (TaCoNA-PHOTONICS 2009)							
3	*Review of the ECONAM project activities in the area of electromagnetic characterization of metamaterials*	*C. Simovski, S. Tretyakov, A. Sihvola*	*11th International Conference on Electromagnetics in Advanced Applications, ICEAA´09*	*Torino, Italy, September 14-18, 2009*			*2009*	*24-26*		No (copyright policy of the publisher)

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities	Main leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
1	School	Vinogradov, A.	General synthesis of metamaterials and their modeling by homogenization	May 5–6, 2008	Marrakesh, Morocco	Electromagnetic, nano-fabrication, optical, material science communities.	Around 40 participants	International
2	School	Kafesaki, M. – Tretyakov, S.	Fabrication and optical properties of nano-structured metamaterials	June 12–13, 2009	Crete, Greece	Electromagnetic, nano-fabrication, optical, material science communities.	Around 40 participants	International
3	School	Sihvola A., Tretyakov S.	Fundamentals of Metamaterials Electromagnetics	November 16-20, 2009	Levi, Finland	Electromagnetic, nano-fabrication, optical, material science communities.	Around 30 participants	International
4	School	Kafesaki, M. – Tretyakov, S.	Experimental Characterization of	13-17 December, 2010	Crete, Greece	Electromagnetic, nano-fabrication,	Around 40 participants	International

			Electromagnetic Metamaterials			optical, material science communities.		
5	Panel session at the Second Congress on Artificial Electromagnetic Materials for Microwaves and Optics, Metamaterials 2008	Schuchinsky, A. and Mittra, R. (organizers)	Theoretical issues and practical aspects of metamaterial characterisation	23-26 September, 2008	Pamplona, Spain	Electromagnetic, nano-fabrication, optical, material science communities.	Around 50 participants	International
6	Special session at META 2010	Vinogradov, A.	Characterization of electromagnetic properties of metamaterials; ECONAM project activity review	22-25 February 2009	Cairo, Egypt	Electromagnetic, nano-fabrication, optical, material science communities.	Around 300 participants	International
7	Special session at the Third International Congress on Advanced Electromagnetic Materials (Metamaterials 2009)	Schuchinsky, A. – Simovski C.	Progress of ECONAM project	August 30 – September 4, 2009	London, UK	Electromagnetic, nano-fabrication, optical, material science communities.	Around 350 participants	International
8	Workshop	ECONAM partners	Educational event for material scientists	December 2009	Brussels, Belgium	Electromagnetic, nano-fabrication, optical, material science communities.	Around 50 participants	European
9	Web based course	Simovski, C.	Characterization techniques for nano-structured electromagnetic materials and their pitfall	March 2011	-	Electromagnetic, nano-fabrication, optical, material science communities.	-	-
10	Monograph	ECONAM partners	Monograph on electromagnetic characterization of nanostructured metamaterials	March 2011	-	Electromagnetic, nano-fabrication, optical, material science communities.	-	-
11	Conference presentations	ECONAM partners	Numerous review talks at international conferences	Whole duration of the project	-	Electromagnetic, nano-fabrication, optical, material science communities.	-	International

Section B

This section (applications for patents, trademarks, registered designs, etc.) is not applicable for a Coordination Support Action Project, because the project activities did not include any research nor development work.

Report on societal implications

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	218696
Title of Project:	Electromagnetic Characterization of Nanostructured Materials
Name and Title of Coordinator:	Ari Sihvola, Professor

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'*	***0Yes 0No***
2. Please indicate whether your project involved any of the following issues (tick box) :	***NO***
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	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	0	1
Work package leaders	0	4
Experienced researchers (i.e. PhD holders)	1	5
PhD Students		
Other		

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**0**
Of which, indicate the number of men:	

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
x	Design and implement an equal opportunity policy	○	○	x	○	○
❑	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)?

○ Yes- please specify

x No

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

x Yes- please specify (web site, explanatory booklets, video courses, doctoral school materials)

○ No

F Interdisciplinarity

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

○ Main discipline: electromagnetics and optics

○ Associated discipline: physics

○ Associated discipline: nanoscience

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.)?

○ No

○ Yes- in determining what research should be performed

○ Yes - in implementing the research

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

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

13b If Yes, in which fields?

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

13c If Yes, at which level?

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

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**This CSA project did not do any research**
To how many of these is open access provided?	
How many of these are published in open access journals?	
How many of these are published in open repositories?	
To how many of these is open access not provided?	
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 ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other: ……………	

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).*	**n/a**

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?	**n/a**
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:

x	Increase in employment, or	x	In small & medium-sized enterprises
❑	Safeguard employment, or	x	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
❑	Difficult to estimate / not possible to quantify		

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:*

Difficult to estimate / not possible to quantify	x

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?

○ Yes x 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	x	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
x	Brochures /posters / flyers	x	Website for the general public / internet
x	DVD /Film /Multimedia	❑	Event targeting general public (festival, conference, exhibition, science café)

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

❑	Language of the coordinator	x	English
❑	Other language(s)		

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

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)
1.3 Chemical sciences (chemistry, other allied subjects)

2 ENGINEERING AND TECHNOLOGY

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)

5. SOCIAL SCIENCES

5.3 Educational sciences (education and training and other allied subjects)

Annex I: List of project participants

Beneficiary number	**Beneficiary name**	**Beneficiary short name**	**Country**
1 (coordinator)	Aalto University School of Electrical Engineering	Aalto	Finland
2	Virtual Institute for Artificial Electromagnetic Materials and Metamaterials - METAMORPHOSE VI AISBL (VI)	VI	Belgium
3	Bilkent University	Bilkent	Turkey
4	Università degli Studi Roma Tre	Roma Tre	Italy
5	QUEEN'S UNIVERSITY BELFAST	QUB	UK
6	University of Glasgow	UoG	UK
7	FOUNDATION FOR RESEARCH AND TECHNOLOGY HELLAS	FORTH	Greece
8	Institute for theoretical and Applied Electromagnetics	ITAE	Russia
9	Karlsruhe Institute of Technology	KIT	Germany