agence d'évaluation de la recherche
et de l'enseignement supérieur

Section des Unités de recherche

Rapport de l'AERES sur l'unité :

Centre de Recherche sur l'Hétéro-Epitaxie et ses Applications – CRHEA

sous tutelle des établissements et organismes :

CNRS

Février 2011

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Le Président de l'AERES

Didier Houssin

Section des unités de recherche

Le Directeur

Pierre Glorieux

Février 2011

Unité

Nom de l'unité : CRHEA

Label demandé : UPR CNRS

N° si renouvellement : UPR10

Nom du directeur : M. Jean-Yves DUBOZ

Membres du comité d'experts

Président :

M. Jean-Michel GERARD, CEA, INAC, Grenoble

Experts :

M. Enrique CALLEJA, Université Polytechnique de Madrid, ETSI, Espagne

M. Gilles PATRIARCHE, CNRS, LPN, Marcoussis

M. Dimitri RODITCHEV, CNRS, INSP, Paris, expert CoNRS

M. Ferdinand SCHOLZ, Université d'Ulm, Institut d'Optoélectronique, Allemagne

M. Xavier WALLART, CNRS, IEMN, Lille

Représentants présents lors de la visite

Délégué scientifique représentant de l'AERES :

Mme Anne RENAULT

Représentant(s) des établissements et organismes tutelles de l'unité :

M. Giancarlo FAINI, DAS Institut de Physique, CNRS

M. Jean-Marc LARDEAUX, VP recherche, Université de Nice

M. Marie-Florence GRENIER-LOUSTALOT, Déléguée régionale du CNRS

Rapport

1. Introduction

- Organization of the visit :

The evaluation of CRHEA was held from Thursday, February 10, 2010 at 10 am to Friday 11 at 5pm. The beginning of the visit was dedicated to the presentation of CRHEA and its scientific report by its director, M. Jean-Yves DUBOZ, followed by one hour presentations of the five teams. For each team, an overview (report + project) by the team leader was completed by one or two highlights on key achievements, presented by team scientists. These presentations generated extensive discussions with the committee.

On thursday afternoon, the committee met the technical staff, the PhDs and post-docs, the CNRS and university research staff in separate meetings.

On Friday morning, the director presented the SWOT analysis of the lab, its objectives, strategy and main inflexions in the research projects and organisation of CRHEA. After discussion, the committee visited the lab equipments and posters in two sub-groups, and met next the representatives of CNRS and of the Nice University.

Closed-door committee meetings were organized on Thursday evening (one hour) and on Friday afternoon (2,5 hours) for internal discussion and preparation of the evaluation synthesis.

The visit was very well organized. The committee wishes to emphasize the excellent atmosphere throughout the visit, the quality of the oral/poster presentations and the lively, rich and fruitful discussions with the staff.

Finally, the committee also acknowledges the excellent quality of the documents which have been provided by CRHEA prior to the visit. The clear, synthetic and complete information about the staff, production, collaborations, contractual projects, of each team has been very precious to evaluate the overalll activity of the laboratory and its impact within the scientific community.

- Short description of the laboratory : history, geographical localization, scientific domain and main activities

The creation of the laboratory can be traced back to 1982, when CNRS implanted a research unit (LPSES) devoted to the development of semiconductor material for photovoltaics within the new scientific park "Sophia Antipolis" in Valbonne (06). In 1992, the thematics of the lab were fully renewed, with an end for solar cell related activities, and started to put an emphasis on wide bandgap semiconductors. It then adopted a novel name, CRHEA.

Nowadays, CRHEA activities are devoted to the development, study and application of large-bandgap compound semiconductor thin films and heterostructures, made of GaN, ZnO or SiC. The main fields of expertise of CRHEA are epitaxial growth using molecular beam epitaxy (MBE) or chemical vapor deposition (CVD), as well as the structural, optical and electrical characterization of semiconductors. Within the recently developped clean-room facility CRHEATEC, it is also able to build simple devices for proofs of concepts or advanced characterization. The laboratory has established over the years numerous collaborations within France as a key supplier of large bandgap heterostructures (especially for GaN based ones) both to academic laboratories and to industrial partners (both large companies and SMEs).

- Management, organisation :

Director of the laboratory : M. Jean-Yves DUBOZ (since 2002)

Over the reporting period, CRHEA was divided into a management service, a technical service (SCR for "service commun de recherches"), and four research teams :

Team 1: ELECTRO (head: M. Yvon CORDIER)	GaN and SiC for electronics
Team 2: OPTO (head : M. Jean MASSIES)	GaN heterostructures for optoelectronics
Team 3: NANO (head: M. Jesus ZUNIGA-PEREZ)	GaN and ZnO based nanostructures
Team 4: OXTRO (head M. Christian MORHAIN)	ZnO for optoelectronics and spintronics

The scientific activity of these four teams and of SCR will be more specifically evaluated in sections 4 to 8 of this report.

- Laboratory Staff :
- Composition :

	in the report 06/10	in the project 01/12
N1 : University research staff	3	3
N2 : CNRS researchers	13	13
N3 : Other researchers including post-docs	5	
N4 : Engineers, technicians and administrative staff (permanent CNRS or university position)	20	21
N5 : Engineers, technicians and administrative staff (others : Novasic)	4	4
N6 : PhDs	10	
N7 : Researchers « habilités à diriger des recherches » or equivalent	6	6

2 • Evaluation of the laboratory

- Overalll evaluation of the lab :

Excellent laboratory having a strategic role on the national level and a very good impact and recognition at the international level.

- Strength and opportunities :

Excellent competences in epitaxial growth, physics and characterization of semiconductor heterostructures and devices

High level fundamental and applied research on material systems with large-scale applications and important potential societal impact; good balance between fundamental and applied oriented projects

Very good scientific production

Strong partnerships with first-class French academic laboratories

Excellent track record for mid and long term collaborations with industry (both large groups and SMEs)

Large and (overalll) well adapted instrumental basis for epitaxial growth, characterization, nanofabrication

High level of external funding, especially from ANR

Very strong support from CNRS (funding, ITA…)

Very good collaboration between teams

Very good management

- Weaknesses and Risks :

Staff size small compared to competitors

Several retirements of senior staff in coming years

Limited attractivity for students and post-docs

Relatively small number of european projects and partnerships

Unsufficient participation at overseas conferences

Weak thematic overlap with physics laboratories from Nice and Sophia Antipolis

- Recommendations :

To CRHEA :

- Increase the focus of your projects, to compensate for the small lab size (see detailed recommendations in team sections)
- Go on developing links with neighbour labs, where possible (structural characterization, CRHEATEC, joint communication oriented toward PhD candidates…)
- Develop more international collaborations (european projects, student exchanges, visiting professors…)

- Increase your participation at overseas conferences; be present at all major international conferences of the field; optimise the impact of your participation at conferences (several communications per participant; presentation of additional posters prepared by colleagues…)
- - Increase the involvement of the CNRS staff in teaching (at universities and engineering schools, first of all in Nice, by not only if opportunities exist in Toulon, Marseille…)
- Increase the collective prospective effort (e.g. yearly brainstorming day)
- Increase the number of meetings between the direction and the staff representatives

To CNRS and Nice University :

- The level of the technical and administrative support looks fine. By contrast, the research staff should be increased. The recruitement of new researchers is crucial, all the more since key senior scientists of the lab (M. J. Massies DR1 CNRS, M. B. Vinter UNSA) will soon retire.
- Epitaxy is a costly activity. Although CRHEA has been highly successful in the quest for external funding, the CNRS grant covers a significant part of the running costs. This support is essential for CRHEA to keep the ability to build its own strategy, especially for the most exploratory part of its research, and should therefore be preserved.
- The committee strongly supports the investment priority of the lab, which is the purchase of a new-generation, high throughput, MOCVD system dedicated to the production of GaN-based epiwafers for the French community. Since the need for such an equipment in France is now well established, and having in mind the key role played by CRHEA over the last twenty years in this matter, CRHEA is the laboratory where this investment should be done.

- Production data:

(cf. http://www.aeres-evaluation.fr/IMG/pdf/Criteres_Identification_Ensgts-Chercheurs.pdf)

A1 : Productive researchers within N1 and N2 (“project”column)	16
A2 : Other producing staff within N3, N4 et N5 (“project” column)	9
A3 : Ratio of productive researchers [A1/(N1+N2)]	100%
A4 : Number of defended HDRs over the period	2
A5 : Number of defended PhDs over the period	10

3 • Detailed comments :

- Scientific quality and production :

CRHEA is a high level research lab, specialized in the fabrication and characterization of large bandgap semiconductor material (GaN, ZnO, SiC) and heterostructures, in view of practical applications. Besides its own research activities, CRHEA is the main provider of GaN-based material to the French academic community, in the framework of scientific collaborations.

In France, this positioning is unique, and can only be compared (to some extent) to the one of the CEA-CNRS Nanophysics and Semiconductors team in Grenoble (GaN, II-Se and II-Te compounds).

Research and development on large bandgap heterostructures has been a very hot topic worldwide, due to the large scale applications of GaN (solid-state lighting, power electronics, devices and sensors for harsh environment…).

Research activities are still flourishing in this domain. Indeed, the degree of mastering of these materials is yet lower than for conventional semiconductors (Si, GaAs, InP…), and further improvement of their quality may have a large impact in application fields. Furthermore, advanced fundamental experiments (single quantum dot spectroscopy, quantum transport…) have become feasible only recently, thanks to the progress of material quality. Such studies aim at a better knowledge of the basic physical properties of these materials, and open novel application prospects.

In this context, CRHEA has produced world-class scientific results over the reporting period. Among the most original or remarkable advances, one can highlight:

- the spectacular improvement of the quality (structural, optical, electrical) of ZnO heterostructures grown on ZnO substrates (OXTRO)
- the development of novel semi-polar GaN templates and AlInN cladding layers for lasers (OPTO)
- the synthesis of graphene on 3C SiC by CVD (ELECTRO)
- the development of high-Q GaN microdisk resonators (NANO)
- the observation of huge Rabi splittings in ZnO or GaN based microcavities in the strong light-matter coupling regime (NANO)
- key contributions to the study of the magnetic properties of ZnCoO and ZnMnO (OXTRO)
- the fabrication of state of the art GaN HEMTs on Si (100) (ELECTRO)
- the development and transfer to industry of excellent detectors for the UV and extreme UV (OPTO)

Seen from a more general point of view, CRHEA has been highly productive, since more than 280 articles have been published in peer-review journals, including 167 regular articles. The number of published regular articles per researcher and per year (2.2) is therefore rather high.

Although 70% of the papers result from collaborations with partners, around 50% of the papers have a first author from CRHEA, which reflects the importance of CRHEA contributions to joint papers, and the strong involvement of CRHEA's staff in the publication effort.

27% of all articles are published within high impact reviews (IF>3) such as Appl. Phys. Lett and Phys. Rev. B. CRHEA researchers have also co-authored several papers in very high impact journals, such as Phys. Rev. Lett. (4), Small (1) and Nano Lett (1). As already mentioned in CRHEA's "project" document, the latter point could still be improved. In particular, basic advances on the controlled epitaxial growth of nanostructures can be published in the best reviews. CRHEA researchers must have the ambition to exploit fully such opportunities.

Although the number of papers varies significantly between researchers, one can note that this production effort involves all researchers and most research engineers as well. No "non producing" researcher (in the AERES sense) can be found at CRHEA. Quite importantly, all PhDs co-sign several publications related to their work at CRHEA.

In terms of communications, the scientific output of CRHEA is also very good. More than 200 communications have been presented by CRHEA's researchers, most of them (80%) at international conferences. However, the participation at conferences could still be optimized, so as to increase CRHEA's visibility. While the participation at conferences within Europe is excellent, the participation at some recent overseas conferences has been too low.

The dynamism of CRHEA is also evidenced by its strong involvement in national collaborative projects (16 ANR, 1 DGA, 1 OSEO) and to a lesser extent European projects (4). Strong long-term collaborations have been established with first-class basic research laboratories, both French (GES Montpellier, LASMEA, IEF Orsay, INAC, Institut Néel and Léti in Grenoble, IEMN Lille…) or European (UPM Madrid, Tyndall in Cork, Bochum university, Glasgow university…)

Quite remarkably, CRHEA also nurtures long-term partnerships with industrial partners, such as ST Microelectronics (GaN power devices), Thales (EUV detectors), Saint-Gobain/Lumilog (substrates for epitaxy). Since 2003, CRHEA endorses for RIBER the training of its new customers on epitaxy systems. Finally, CRHEA hosts and collaborates tightly with a team of 4 engineers from the NovaSiC company, which develops a novel reactor for the epitaxial growth of SiC on large substrates.

Ten PhD trainings have been successfully completed over the reporting period. Due to the relatively weak PhD recruitment possibilities in Nice, most students come from other French (60%) or foreign (30%) universities. A master and PhD exchange program has been established with Bochum University. Further efforts at the European (and worldwide) level should be performed in the future to increase the number of PhDs. Two HdRs have also been prepared by researchers since 2006.

- Attractivity and recognition :

The recognition of the laboratory is excellent at the French level and very good internationally. This is assessed by:

- The overalll good impact of CRHEAs paper's (citation rates) and researchers (H factors)
- The presentation by CRHEA researchers of 22 invited talks at international conferences
- The organisation by CRHEA researchers of 2 national and 2 international conferences
- The numerous collaborative research projects of CRHEA with academic as well as industrial partners, the strong increase of its contractual resources (>1.5 M€ in 2010, +100% since 2006)
- The active participation of CRHEA at the thematic network OPTITEC/POPSUD (pôle de compétitivité); CRHEA is also an active member of the microscopy network "METPACA". It is also a co-founder of the "C'Nano PACA" nanoscience network, and is heading the CT-PACA nanotechnology network, and the CRHEATEC regional technology facility.
- The award of the prestigious Silver Medal of CNRS to M. Jean MASSIES

- Management and life of the laboratory

The laboratory has been reorganized in depth in 2006. With the very recent suppression of the OXTRO team, the research teams are now organized by application domain (ELECTRO, OPTO, NANO) and completed by two services, for characterization and administrative/logistic support. This organization is well adapted to the size and objectives of CRHEA. For instance, it helps and will help CRHEA in taking full benefit of its broad expertise in epitaxy, through fruitful combinations of materials (ZnO+GaN) or techniques (MBE+CVD).

To manage the laboratory, the director works in strong interaction with the team heads. The annual budget and major topics of general interest are discussed during ad hoc general assemblies of the laboratory. The director also organizes meetings of the statutory laboratory council several times (3-4) per year. These meetings do not appear to be the main communication tool between the staff and the direction; this is likely due to the small size of the lab which favours direct interactions and to the important role of the team heads. An increase of the number of meetings of the lab council looks desirable. Similarly, the number of general meetings devoted to scientific brainstorming should be increased. Nevertheless, information and consultation in the lab looks overalll very good. Most importantly, discussions of the committee with the staff have highlighted a strong support to the strategic positioning and orientations of the lab, and strong confidence in the head of the lab.

CRHEA is well involved in external communication initiatives toward the general public (conferences and debates, expositions,...).

Concerning teaching, the involvement of the CNRS staff is relatively weak and should be increased. By contrast, the training of PhDs and post-docs to epitaxy should be seen as an important specific contribution of CRHEA.

Finally, CRHEA has played a leading role in several actions aiming at structuring research at the local and regional scales (C'Nano PACA, METPACA, open CRHEATEC technology facility…). It is also presently building the new federative institute Döbling which will gather the physics labs of Nice University.

- Evaluation of the project and strategy :

CRHEA has a very clear strategy for the future. Its ambition is exploiting its expertise and mastering of the epitaxy of large bandgap materials to produce high level basic research and develop novel applications of these strategic materials. Due to its small size, CRHEA specializes in the epitaxy and characterization, and develops its research in the framework of tight collaborations with academic and industrial laboratories bringing complementary skills and expertise. On the national level, CRHEA behaves as an essential facility for the delivery of GaN based material, heterostructures and devices to the scientific community (once again in the framework of collaborations structured by shared goals).

Therefore, the main objectives of CRHEA are :

- to produce high level basic and applied scientific results with partners
- to exploit application opportunities with industrial partners
- to provide expert training in epitaxy and characterization to PhDs and post-docs, for the benefit of the French and European laboratories and industries.

This strategy has been fruitful over the last years and is still fully relevant. Large bandgap semiconductors are obviously strategic materials. The exploration of their physical properties and novel potential applications and the improvement of existing devices (LEDs, power electronic devices) are hot topics worldwide. CRHEA's specialization strategy in epitaxy and characterization is also well adapted due to the relatively small lab size.

The scientific project presents a good balance between continuity and novelty. Less promising research on GaInAsN has recently been stopped. Recent advances in material mastering will be exploited to address very attractive challenges with potential worldwide impact, such as, to list a few :

- - the growth of graphene films on 3C-SiC,
- - Bose-Einstein condensation of polaritons in ZnO-based hybrid planar microcavities
- - ferromagnetism mediated by a hole gas in ZnMnO
- - light sources, including lasers, to bridge the "green" gap
- - electronic devices based on GaN planar and nanowire heterostructures

As presented in the "Project" document, the research project is very rich, but likely too broad for CRHEA. The committee acknowledges significant efforts to focus CRHEAs objectives (stop of GaInAsN work, research on SiC epitaxy endorsed by NovaSiC researchers…). Nevertheless, an improved focus of the teams' goals is still necessary (see detailed discussions in team sections).

Thanks to the support of CNRS and its ability in raising external support (from ANR, industry…), CRHEA has successfully developed over the years a large set of tools for epitaxy, characterization and micro/nanofabrication. These tools are overalll well adapted to the project. Nevertheless, several needs have been identified by CRHEA:

- an additional MBE reactor will be dedicated to ZnO (through the retrofit of the GaInAsN dedicated one);
- a new generation high throughput MOCVD reactor is needed to better cover the needs of the national community in GaN based heterostructures, and ramp up (through the reallocation of the existing system) internal activities on GaN nanowires.

    - the replacement of the old transmission electron microscope by a new one is also needed

The committee strongly supports the lab priority, which is put on the purchase of this new MOCVD reactor. It also feels that CRHEA must keep in the long term access to standard TEM equipment on site. Possibilities to share a new TEM with neighbour laboratories should be considered. Increased access to new generation TEM/STEM microscopes is recommended, e.g. through the on-going collaborations with CINAM (Marseille) and PFNC (Grenoble) within the METSA network.

4 • TEAM 01 : ELECTRO

- Head of team : M. Yvon CORDIER
- Team composition :

	in the report 06/10	in the project 01/12
N1 : University research staff	-	-
N2 : CNRS researchers	2	2
N3 : Other researchers including post-docs	3	
N4 : Engineers, technicians and administrative staff (permanent CNRS or university position)	1	2
N5 : Engineers, technicians and administrative staff (others : Novasic)	4	4
N6 : PhDs	3	
N7 : Researchers « habilités à diriger des recherches » or equivalent	1	1

The ELECTRO group is a rather peculiar one since, for the period under consideration, it brings together 2 CNRS staff (1 DR and 1 IR) and 2 engineers and 2 technicians from NovaSiC, a company specialized in SiC surface polishing. Recently, at the beginning of 2010, the group has been reinforced by a young CNRS researcher. The activity is devoted to the growth and study of wide band gap materials for electronics.

The group has developed high-level skills in the growth of cubic 3C-SiC on silicon substrates as well as a high mastering degree in the growth of thick crack-free nitride layers on various substrates. The resulting 3C-SiC/Si templates have allowed ELECTRO initiating recently a new topic related to the epitaxy of graphene on 3C-SiC, which represents an original approach for the “hot topic” of graphene growth. Nitride layers with corresponding AlGaN/GaN heterostructures have lead to promising perspectives for GaN integration with silicon technology.

- Scientific quality and production

The scientific production is very good, with a marked increase during the past 3 years, reaching about 100 publications in international journals covering both material/physical topics and electronic ones.

The SiC activity has been focused on the CVD epitaxy of 3C-SiC on silicon and thanks to its accumulated experience, the group is now leader in France in this field, allowing to dispose of the interesting mechanical and electrical properties of SiC at low cost. This has led to a major contract with ST Microelectronics with respect to power electronics. More recently ELECTRO has initiated an original activity of graphene growth on 3C-SiC on silicon and reported the first CVD epitaxy of graphene on 3C-SiC. It is worth noting that this approach is probably the main one allowing the integration of a graphene film on silicon without relying on report processing.

The nitride growth has been oriented towards power electronics. Thanks to a high degree of control of the strain during growth and subsequent cooling, thick (up to 4 µm) GaN crack free layers have been grown by MBE on silicon for applications in Schottky rectifiers (once again part of the contract with ST Microelectronics). Regarding AlGaN/GaN HEMT devices, beside the optimization of the structure on various buffer layers, the focus has been put on the integration with the silicon technology and a state-of-the art result for power HEMTs on Si(001) has been obtained.

A particular strength of ELECTRO is its strong relations with industrial companies, leading to 5 significant partnerships with major companies (ST, Freescale) as well as with SMEs (Riber, Picogoga, NovaSiC). In all cases, these partnerships are mid or long-term ones, demonstrating their quality, further evidenced by 3 patents.

- Recognition and attractivity :

The international visibility is good with 11 Invited conference talks, including one at the International Conference on Molecular Beam Epitaxy, the major conference in the field. ELECTRO attracts a significant number of post-docs from France and abroad and in 2010 has attracted a young CNRS researcher. 2 PhD theses have been defended during the period and 4 PhDs are currently working in the group, which represents a significant improvement.

The group is strongly implicated in French research projects: 4 projects executed during the period and 5 projects still running. Besides ANR projects, a large project has also been granted to Novasic and CRHEA by OSEO.

Novasic researchers are involved in 3 European projects on SiC, which highlights the importance and visibility of this activity at the European level.

- Evaluation of the project :

ELECTRO has recently benefitted from the arrival of a CNRS engineer. The group includes now four CNRS staff (1 DR, 1 CR and 2 IR) and two engineers and two technicians from NovaSiC. The scientific project covers the various skills of the group. New applications for cubic SiC on silicon are considered, namely for MEMS, electronic devices such as MOS transistors and as pseudosubstrates for non polar nitride growth. The latter should be coordinated with the NANO and OPTO groups.

The recent success demonstrated in CVD graphene growth is pushed forward with the elaboration of graphene-based heterostructures.

In continuity with previous work, nitride growth will be oriented towards high frequency and high power electronics. Although this field is very competitive, ELECTRO has gained an international recognition, especially as regards the growth on Si(001). Future work should aim at consolidating this position and going further in the integration with silicon technology.

Finally, the investigation of the vertical transport in nitride heterostructures is an emerging and very interesting topic. It deserves to be addressed in collaboration with the NANO group, with emphasis on nanowire structures.

The committee recommends looking carefully at the balance between industrial-related activities and those with more scientific added value. More precisely, the CNRS staff is encouraged to focus on the most promising topics of their activity, namely:

- GaN and related HEMT structure growth on Si(001)
- vertical transport in GaN heterostructures
- graphene epitaxy

- Conclusion :

  - Overalll evaluation of the team :

- Very good quality of the staff and of the scientific production
- One of the main national actors in nitride growth for power electronics

  - Strengths and opportunities :

- industrial collaborations, contracts and patents
- high expertise in GaN and SiC epitaxy on Si for power electronics
- ability to combine CVD and MBE growth techniques
- original graphene growth technique

  - Weaknesses and threats :

- only 2 CNRS researchers in the group
- few collaborations with physicists specialized in electronic transport

  - Recommendations :

- look carefully at the balance between industrial-related activities and those with more scientific added value
- focus on the most promising topics of the activity, namely graphene epitaxy, GaN and related HEMT structure growth on Si(001), vertical transport in GaN heterostructures
- reinforce basic-oriented research by increasing external collaborations with high level physics groups (e.g. on quantum electronic transport)

5 • TEAM 02 : OPTO

- Head of team : M. Jean MASSIES (report period) – M. Fabrice SEMOND (next period)
- Team composition :

	In the report 06/10	In the project 01/12
N1 : University research staff	1	2
N2 : CNRS researchers	4	5
N3 : Other researchers including post-docs	1	
N4 : Engineers, technicians and administrative staff (permanent CNRS or university position)	3	3
N5 : Engineers, technicians and administrative staff (others)	-	-
N6 : PhDs	3	
N7 : Researchers « habilités à diriger des recherches » or equivalent	1	3

The group "OPTO" currently consists of 4 CNRS researchers, 1 Ass. Pr., 3 CNRS ITAs, 3 PhD students and one post-doc. It has hosted 7 post-docs since 2006.

Over the reporting period, the OPTO team has been involved in the following major research topics:

1- Non- and semipolar nitrides

2- Light sources for bridging the green-yellow gap / green lasers

3- Quantum dot based light emitting diodes for the visible and the UV

4- Materials for UV and EUV detection

5- Monolithic white light emitting diodes

6- Dilute nitrides (InGaAsN)

- Scientific quality and production :

Some of OPTO's research axes address very hot challenges within the scientific community e.g. the development of green lasers, UV light sources, or low-cost white LEDs. The developments that are undertaken on the materials' side are also fully relevant.

Recently, a very clever method has been developed how to realize large area semipolar GaN structures. By etching trenches with c-plane sidewalls into a sapphire wafer, epitaxial GaN growth in c-direction inclined to the top surface can be established leading to excellent semipolar GaN layers after coalescence. This is certainly a very important building block on the way to bridge the "green gap" of light emitters. The first realization of a laser structure containing AlInN as wave-guiding material may help to solve the problem of decreasing refractive index contrast in laser diode structures with emission wavelengths approaching or surpassing 500 nm. Moreover, OPTO has succeeded to develop light detectors for the EUV and x-ray wavelength regime based on AlGaN heterostructures with excellent properties. Similarly, the basic studies on GaN/AlGaN QDs are regarded as very important.

These activities are all nicely embedded into the technological possibilities of CRHEA and also fairly well connected to the on-going activities of the other groups ("ELECTRO" and "NANO"). Work concentrates very strongly on epitaxy where two methods are available: MOVPE and MBE. Within CRHEA, the most important additional semiconductor technology is also available along with the respective characterization methods (photoluminescence, x-ray, electron microscopy including TEM etc.)

The "OPTO" team performs high quality research on these fields, which is documented in their recent publications (about 75 peer-reviewed journal publications in the last 5 years, most of them in the major scientific journals of the field, such as Applied Physics Letters (21), J Applied Physics (15) or Physical Review B (11)). One patent on an original approach toward white light LEDs has been filed.

OPTO researchers are also overalll well involved in the presentation of their research at the major international conferences of the field (more than 100 conference contributions overalll, including 10 invited ones).

The scientific results of the group OPTO are in most cases of best international level. Some of them are definitely recognized as major contributions to the respective field and have found world-wide attention, like, e.g., work on "nitrides used as detector material in the EUV region" (5 invited talks) and the studies on "semipolar GaN on structured sapphire wafers". However, others, while being very good research, did not find such international recognition.

- Recognition and attractivity :

Overalll, the OPTO team has an excellent recognition at the national level; some of its activities are highly visible internationally. Invitations at international workshops or major national conferences (J3N, JNCO) have been obtained for the work on UV and EUV detectors (4), monolithic white LEDs (1) and green lasers (1) for instance. The leader of the group, J. Massies, has been awarded the prestigious Silver medal of CNRS.

Although OPTO's scientific production is excellent for a team of that size, its recognition at the international level may have suffered from a relative thematic dispersion. The number of (highly competitive) topics covered by the team is too large, and these topics are not all strongly connected or interrelated. In consequence, OPTO has achieved very good scientific results on these particular fields, but failed to some extend to become THE reference laboratory world-wide for one of these major topics. A better thematic focus is therefore recommended for the future (see below).

The OPTO team is very well integrated within the national community, and has numerous collaborations with high level academic partners. OPTO took part to 4 ANR projects, one ERA-SPOT European project and one ESA project over the period.

OPTO has established mid and long term links with industrial partners such as Saint-Gobain/Lumilog, Thales TRT and TED (EUV detectors) or Telecom Research and Development Malaysia (InGaAsN lasers).

- Evaluation of the project :

The OPTO group is definitely strengthened by the restructuring of CRHEA and the integration of a part of the former OXTRO group. Nearly all research topics in its future focus (non- and semipolar nitrides, light sources for bridging the green-yellow gap including green lasers, quantum dot based UV light emitting diodes, materials for UV and EUV detection) are of major scientific and industrial importance world-wide and should hence be continued with strong engagement. The decision not to continue research on dilute nitrides is fully relevant, and will help to strengthen the other topics substantially. Similarly, OPTO may reduce its efforts towards ZnO which seems not well-suited for solid-state lighting, but fits better into NANO activities. Owing to the excellent scientific and technological basis formed over the recent years, the OPTO team can certainly strongly benefit from many synergetic links between these main topics mentioned above. As an example, the “green gap” topic will gain scientific weight by a closer integration of (up to now more or less stand-alone) pre-studies like white light emitting LEDs requiring optimized "green" quantum wells, semipolar GaN on structured sapphire, and AlInN as cladding layer for green lasers.

- Conclusion :

  - Overall evaluation of the team :

Very experienced researchers with excellent international reputation

  - Strengths and opportunities :

High quality of the staff

Large material expertise, ability to combine MOVPE, HVPE and MBE

Societal needs and large markets related to GaN opto devices (solid-state lighting, visible lasers, UV devices)

  - Weaknesses and threats :

Small size compared to competitors

Difficulty to find industrial partners for valorization in LED/laser fields

Participation at overseas conferences

International visibility

  - Recommendations :

Improve the focus of the project, with emphasis on green light emitters and UV light detectors.

Try to integrate and combine your many sub-topics in such main subjects. This will help to increase your visibility on an international level…

Increase and optimise your participation at the main international conferences of the field

6 • TEAM 03 : NANO

- Team leader : M. J. ZUNIGA-PEREZ
- Team composition

	In the report 06/10	In the project 01/12
N1 : University research staff	-	1
N2 : CNRS researchers	4	4
N3 : Other researchers including post-docs	-	
N4 : Engineers, technicians and administrative staff (permanent CNRS or university position)	3	3
N5 : Engineers, technicians and administrative staff (others)	-	-
N6 : PhDs	2	
N7 : Researchers « habilités à diriger des recherches » or equivalent	1	0

Over the reporting period, the group "NANO" consisted of 4 permanent scientists, 3 engineers and technicians, 2 PhD students and 2 Technicians. One CNRS researcher form LPMC Nice also contributes (part time) to NANO activities. NANO has also hosted 4 post-docs.

The main activity of this group is the fabrication and characterization of epitaxial nanostructures based on GaN and ZnO for nanophotonics and to a smaller extent nanoelectronics. NANO implements the two most common epitaxial systems, namely, MBE (ammonia) and MOVPE. Concerning GaN, the group addressed the growth and study of GaN nanowires, core-shell nanostructures, photonic crystals, micro disks and cavities… ZnO activities are mostly related with the development of planar microcavities in the strong light-matter coupling regime, including noticeably hybrid GaN/ZnO microcavities.

Recently, a major part of the group OXTRO merged within NANO, so that a better coordination on the work based on ZnO has been achieved.

- Scientific quality and production :

This group has developed a very strong effort on hot topics with very high scientific value and relevance. Of particular relevance are activities related to GaN based photonic crystals, micro disks and cavities, and NWs. Very relevant results on the matter-light coupling (strong and weak regimes) have been pursued, with excellent results that are top rated at international level.

Work on GaN NWs SAG (Selective Area Growth) by MOCVD is excellent. The demonstration of the merging of NWs into a continuous GaN layer (pseudo-substrate) with reduced dislocation density is particularly important and attractive. ZnO based studies on nanophotonics are as well very relevant.

Publication rates are very high, steadily increasing over the past 3 years, with a strong collaborative component with other national and international teams. Excellent publication ratio per permanent researcher (4.9 regular articles per researcher and per year on average, one third being published in reviews with an IF>3).

- Recognition and attractivity :

Overalll, the NANO team has an excellent recognition at the national level; some of its activities are highly visible internationally, with invitations at international workshops or major national conferences. NANO has good collaborations on the national level (3 ANR projects over the period). As mentioned, international visibility is also quite high, with links and scientific collaborations with several Institutions and Research Centers in Europe and participation in three research projects from the EU, including one with a strong industrial partnership. Two out of the three international exchanges from CRHEA in the period were from NANO members.

These activities should enhance attractiveness to new PhD candidates from all over the world, as well as that from the team members.

- Evaluation of the projet :

With the merging of part of OXTRO within NANO, the team will be reinforced by two CNRS researchers. Also, spintronics-related projects on ZnO will be conducted within NANO in the future.

The topics to be addressed by NANO are very hot and relevant; the selected goals take advantage of recent advances of CRHEA (homoepitaxy of weakly doped ZnO or high quality ZnO/ZnMgO heterostructures) or strong opportunities (ability to combine GaN and ZnO, MOCVD and MBE, new substrate patterning capabilities at CRHEATEC, new magneto-optics set-up for ZnO…).

Several projects presented by NANO look particularly attractive:

- thanks to recent quality improvements, ZnO and GaN based optical microcavities are now well suited for quantum optics experiments, and noticeably for Bose-Einstein polariton condensation at room temperature
- novel strategies to build ZnO-heterostructures containing a hole gas are proposed; these structures will very likely permit to know whether a ferromagnetic behaviour mediated by holes can be achieved in ZnMnO, and close a long-lasting controversy on that topic.
- the development of novel nanowire heterostructures for photonics and electronics will strongly benefit from the unique panel of growth techniques and expertise present at CRHEA.

In addition to these basic oriented projects, the proposed actions on NanoFETs, and potential expansion toward Nanodevices is also excellent. The strategy of the proposed project is overalll very adequate and feasible.

- Conclusion :

  - Global evaluation :

Excellent team

  - Strengths and opportunities :

- high quality of the staff
- in good position to address hot challenges (Bose-Einstein condensation of polaritons, ferromagnetism in ZnMgO…)
- combination of techniques or materials within nanowire heterostructures
- European collaborations

  - Weaknesses and risks :

- saturation of MBE ZnO and GaN MOCVD equipments
- small size vs competitors

  - Recommendations :

- Reinforce work on Nanowires and their applications, e.g. towards nanodevices and nano-sensors (bio).
- Coordinate efforts and clarify role interactions with ELECTRO and OPTO concerning work on polar and non-polar GaN pseudo-substrates (i.e. NANO is also producing them by NW merging) and nanoFETs, RTDs, nanoneedles (THz).
- Coordinate efforts and clarify role interactions with OPTO concerning work on nanostructures (NW, QD, WLEDs, etc.); on polar and non-polar GaN pseudo-substrates; and on ZnO /GaN.
- Need to hire new staff members in NANO.
- Need for an increased access to epitaxial systems (ZnO MBE, GaN MOCVD).
- The team could consider working also on InGaN, which would expand capability and attractiveness.

7 • TEAM 03 : OXTRO

- Head of team : M. Christian MORHAIN (report period)
- Team composition

	In the report 06/10	In the project
N1 : University research staff	2	-
N2 : CNRS researchers	2	-
N3 : Other researchers including post-docs	1	-
N4 : Engineers, technicians and administrative staff (permanent CNRS or university position)	-	-
N5 : Engineers, technicians and administrative staff (others)	-	-
N6 : PhDs	-	-
N7 : Researchers « habilités à diriger des recherches » or equivalent	1	1

During the reporting period the group "OXTRO" consisted of 2 permanent scientists, 2 professors and 1 Post-doctorate student.

- Scientific quality and production :

Over the reporting period the OXTRO team has been involved in the research topics related to the studies of structural, electronic and magnetic properties of ZnO-based nano-structures. Specifically, the high-quality epitaxial growth of ZnO had been achieved in CRHEA already in 2004, and thus, the essential efforts were concentrated on revealing the relationship between the structure/organisation of ZnO devices and their electronic (mainly optical) properties. The main topics of this activity were:

1. Diluted ZnO-based magnetic alloys
2. ZnO/ZnMgO quantum wells on polar and non-polar substrates
3. Homoepitaxial growth of ZnO-thin films on crystalline ZnO substrate
4. Doping issues in ZnO

All these topics have been advanced significantly, however the most important results concern the topics 1 and 3 which are among the very hot challenges within the scientific community. First, the experimentally proven absence of the theoretically predicted ferromagnetism at room temperature in the diluted (Zn,Co)O alloys is a very important achievement; here, the contribution of the team in the progress of the comprehension of the magnetism was essential for the community.

The second main result concerns the remarkable improvement of the quality of ZnO epilayers grown on ZnO substrates instead of standard sapphire substrates. For such epilayers, OXTRO has demonstrated an improved surface roughness and crystalline quality, a record low photoluminescence linewidth and high emission yield thanks to the reduction of the number of defects, and a drastically reduced residual n-type doping. The latter result is particularly important, as it may enable a sizeable p-type doping of ZnO, which is nowadays the major bottleneck for applications of ZnO in optoelectronics.

The "OXTRO" team performs high quality research on these fields, which is documented in their recent publications (about 22 peer-reviewed journal publications in the last 5 years, most of them in the major scientific journals of the field, such as Physical Review Letters (3), Applied Physics Letters (6) or Physical Review B (6)). Importantly, the papers of the team are largely cited, well above the impact factor index of the corresponding journals. The research results of the team were presented as invited talks at 9 international conferences (including ICPS, the largest conference devoted to semiconductor physics) or workshops.

- Recognition and attractivity

Overalll, the OXTRO team has an excellent recognition at the national level; it is partner of 3 ANR projects and of one bi-lateral contract. The team established numerous collaborations with European teams (Poland, Spain, Germany). However, the number of the directed PhD thesis is clearly unsatisfactory; it is consistent neither with the very high quality of the research nor with the presence of one professor and one assistant professor in this team.

- Evaluation of the project

The CRHEA project suggests OXTRO team to split in two parts and to integrate the teams NANO (M. Ch. Morhain, M. Ch. Deparis) and OPTO (M. B. Vinter, M. J.-M. Chauveau). The committee fully supports this decision, mainly motivated by the small team size.

The relevance and interest of ZnO-related projects are discussed in OPTO and NANO parts.

- Conclusion :

Taking into account its small size, the OXTRO team has shown over the report period a very high research performance. The publications of the team are of excellent quality and strongly cited by the international research community.

8 TEAM "SERVICE COMMUN DE RECHERCHES(SCR)"

- Head of team : M. Philippe VENNEGUES (report period) – M. Philippe VENNEGUES (next period)
- Team composition :

	In the report 06/10	In the project
N1 : University research staff	-	-
N2 : CNRS researchers	1	1
N3 : Other researchers including post-docs	-	-
N4 : Engineers, technicians and administrative staff (permanent CNRS or university position)	6	6
N5 : Engineers, technicians and administrative staff (others)	-	-
N6 : PhDs	-	-
N7 : Researchers « habilités à diriger des recherches » or equivalent	2	2

The "Service Commun de Recherche" currently consists of 1 researcher, 3 research engineers and 4 technicians, all with permanent positions.

- Scientific quality and production

The joint service research "SCR" seems to play its role perfectly as internal technology and characterization facility, supporting CRHEA's research projects. The large number of samples characterized shows the strong involvement of this service in the laboratory. The own research activity of "SRC" mainly concerns the structural characterization by TEM, and specifically the study of structural defects in AlN/GaN heterostructures and ZnO epitaxial layers grown on sapphire, subjects where these works are recognized as referring. In particular, the quality of work concerning the detection of the phase separation in the AlGaN barriers covering the GaN QDs should be emphasized. This study uses a local and quantitative lattice measurement by HRTEM; a mechanism, based on the elastic energy minimization, is proposed to explain the phase separation observed.

The "SRC" team brings key contributions to the structural and optical characterization of CRHEA's materials and nanostructures, as evidenced by its participation to 57 peer-reviewed journal articles during the last 5 years, most of them in the major scientific journals of the field (material science, physics of crystal growth, physics of extended defects...) such as Applied Physics Letters (19), Journal of Applied Physics (11) or Physical Review B (8). SRC scientists have also signed as first authors 5 peer-reviewed journal articles over the period.

- Recognition and attractivity :

This item is not relevant for the core activity of SRC, as a characterization service.

The visibility of the SRC's own research activities (structural characterization and study of defects) is already very good. It could nevertheless be further increased through a higher participation in international conferences.

- Evaluation of the project :

SCR will keep the same missions in the future. The main evolutions are related to the recent purchase of new equipment (e-beam writing system Raith on a SEM (2010), reactive ion etching (2011)) for the CRHEATEC micro/nanofabrication facility and a cathodoluminescence set-up for optical characterization (2010).

CRHEA considers that CRHEATEC will be fully equipped to satisfy its major needs in the field of micro/nanofabrication. The major investment project of SCR is related to the replacement of its old (16 years) transmission electron microscope (TEM).

The Committee emphasizes the following points:

- Concerning structural characterization, it is clear that CRHEA must keep TEM competences and standard TEM equipment on site. In the mid-term, the replacement of the existing TEM by a new one will be necessary. Possibilities to share this equipment with neighbour laboratories should be considered. A large access to new generation TEM/STEM microscopes, equipped with aberration correctors, is relevant and necessary to continue developing a high level research. The committee strongly encourages the on-going collaborations with CINAM (Marseille) and PFNC (Grenoble) within the METSA network.
- The acquisition of the new machine ICP/RIE is obviously an important point for the development of the technological activities of the laboratory. With its new equipments, CRHEATEC will be a very interesting resource for CRHEA and its partners in the future.
- The recent development of a cathodoluminescence set-up is an excellent decision; well adapted to the characterization of large bandgap material, this set-up will enable to establish stronger links between structural and optical properties of GaN-based nanostructures.

Intitulé UR / équipe	C1	C2	C3	C4	Note globale
UPR10 - Centre de recherche sur l'hétéroepitaxie et ses applications	**A+**	**A**	**A+**	**A**	**A+**
ELECTRO	A+	A	Non noté	A	A+
OPTO	A+	A	Non noté	A	A+
NANO	A+	A+	Non noté	A+	A+
OXTRO	Non noté	Non noté	Non noté	Non noté	Non noté

C1 Qualité scientifique et production

C2 Rayonnement et attractivité, intégration dans l'environnement

C3 Gouvernance et vie du laboratoire

C4 Stratégie et projet scientifique

Statistiques de notes globales par domaines scientifiques

(État au 06/05/2011)

Sciences et Technologies

Note globale	ST1	ST2	ST3	ST4	ST5	ST6	Total
A+	6	9	12	8	12	11	58
A	11	17	7	19	11	20	85
B	5	5	4	10	17	8	49
C	2	1	2				5
Total	**24**	**32**	**25**	**37**	**40**	**39**	**197**
A+	25,0%	28,1%	48,0%	21,6%	30,0%	28,2%	29,4%
A	45,8%	53,1%	28,0%	51,4%	27,5%	51,3%	43,1%
B	20,8%	15,6%	16,0%	27,0%	42,5%	20,5%	24,9%
C	8,3%	3,1%	8,0%				2,5%
Total	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%

Intitulés des domaines scientifiques

Sciences et Technologies

ST1 Mathématiques

ST2 Physique

ST3 Sciences de la terre et de l'univers

ST4 Chimie

ST5 Sciences pour l'ingénieur

ST6 Sciences et technologies de l'information et de la communication