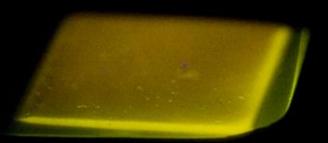
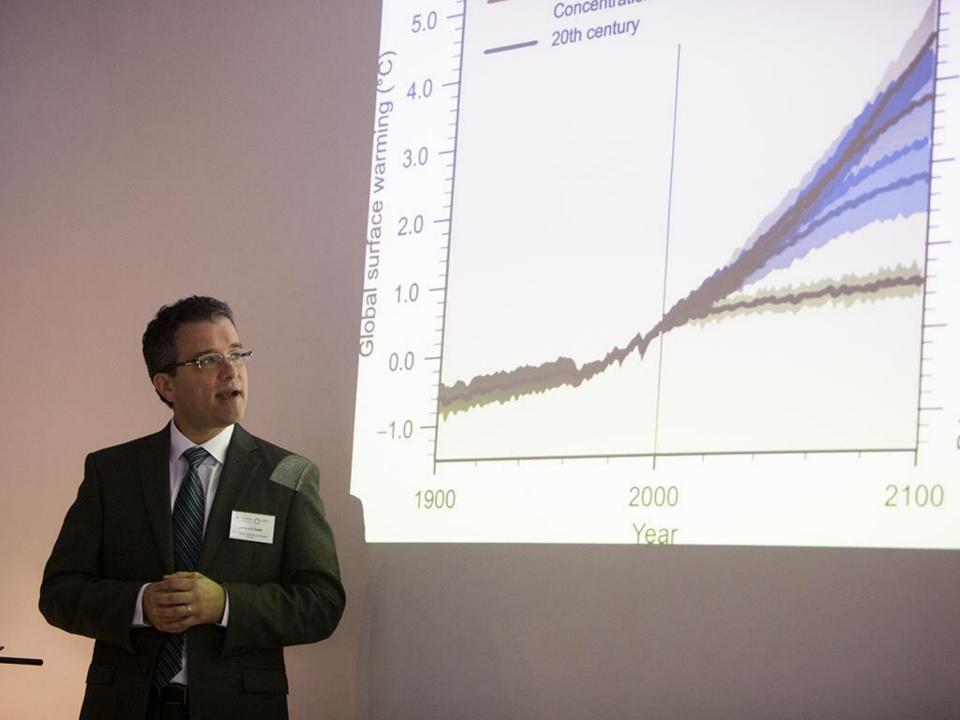




# **NORLED : N-Inner (ii) project** Nordic Light Emitting Diode Initiative

### Fluorescent silicon carbide for white LEDs









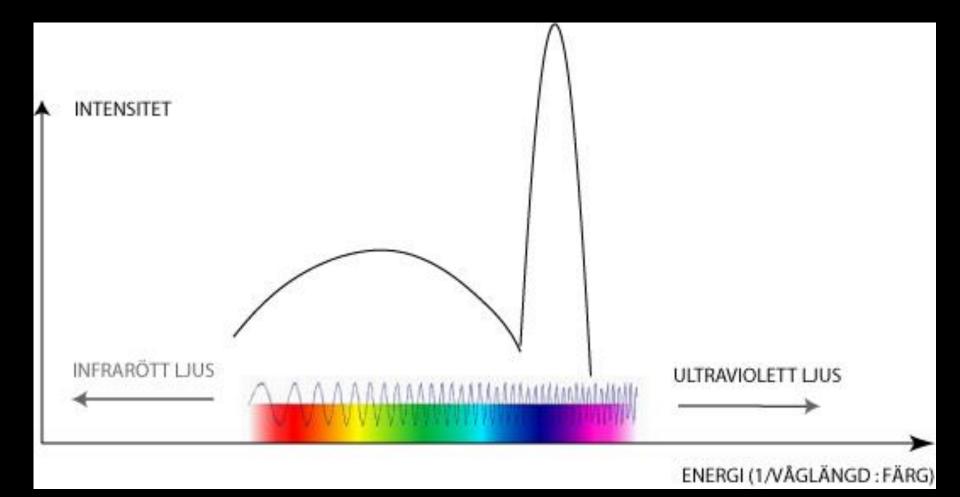
# white LEDS







# **Phosphor conversion**

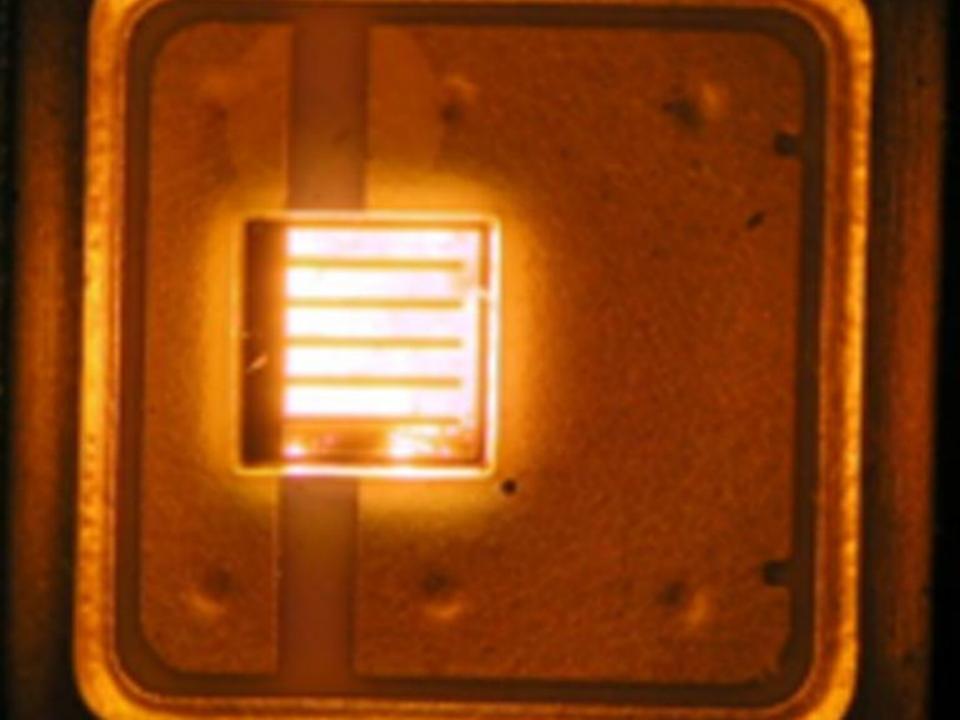


# **BLUE TONE**

# BINNING

# DROOP







#### COMPREHENSIVE SEMICONDUCTOR SCIENCE AND TECHNOLOGY

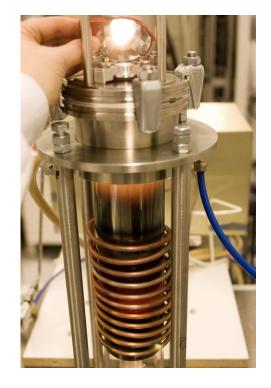
### **3.05** Sublimation Epitaxial Growth of Hexagonal and Cubic SiC

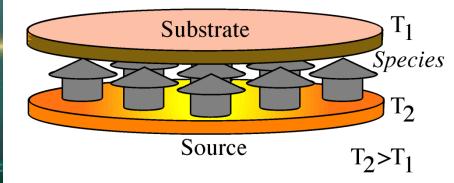
M Syväjärvi and R Yakimova, Linköping University, Linköping, Sweden

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Volume









# 1907



#### A Note on Carborundum.

#### To the Editors of Electrical World:

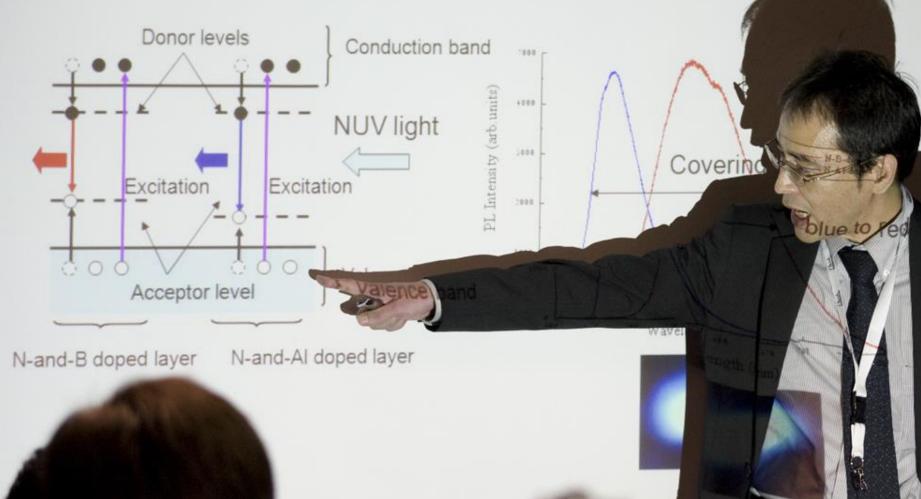
STRS :--During an investigation of the unsymmetrical passage of current through a contact of carborundum and other substances a curious phenomenon was noted. On applying a potential of 10 volts between two points on a crystal of carborundum, the crystal gave out a yellowish light. Only one or two specimens could be found which gave a bright glow on such a low voltage, but with 110 volts a large number could be found to glow. In some crystals only edges gave the light and others gave instead of a yellow light green, orange or blue. In all cases tested the glow appears to come from the negative pole. a bright blue-green spark appearing at the positive pole. In a single crystal, if contact is made near the center with the negative pole, and the positive pole is put in contact at any other place, only one section of the crystal will glow and that the same section wherever the positive pole is placed.

There seems to be some connection between the above effect and the e.m.f. produced by a junction of carborundum and another conductor when heated by a direct or alternating current; but the connection may be only secondary as an obvious explanation of the e.m.f. effect is the thermoelectric one. The writer would be glad of references to any published account of an investigation of this or any allied phenomena.

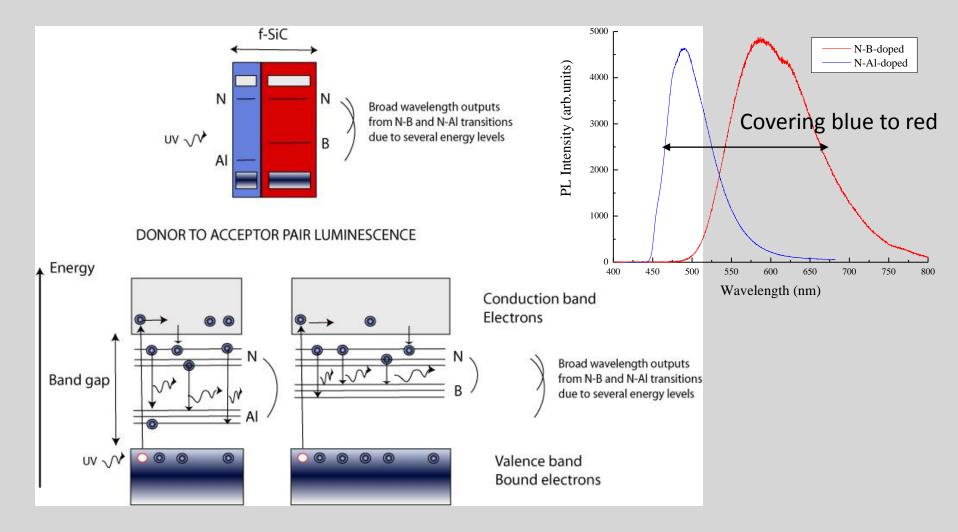
NEW YORK, N. Y.

H. J. ROUND.

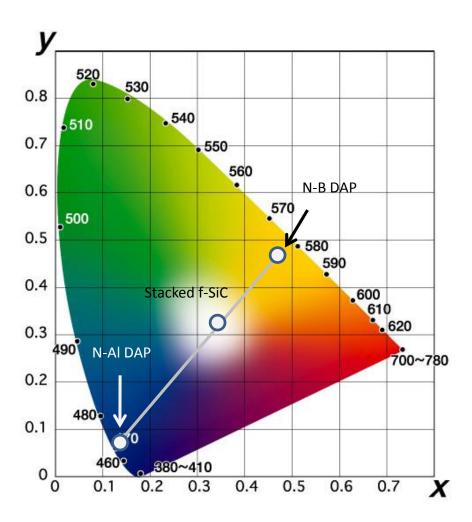
# White light generation using DAP recombination in SiC



# White light generation using silicon carbide

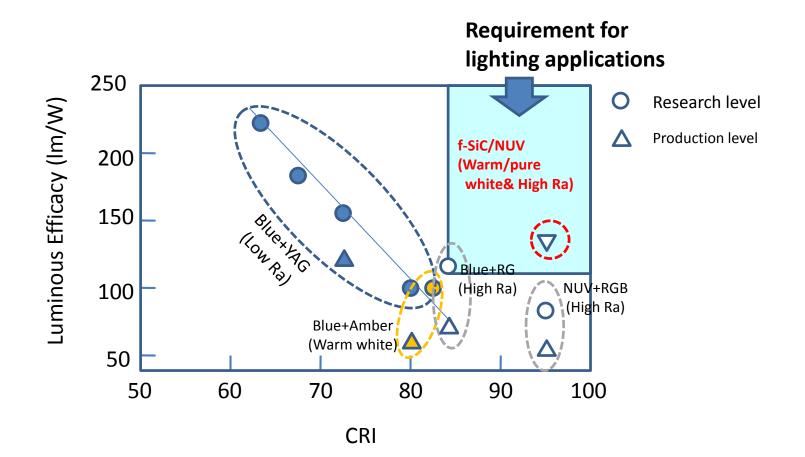


# **CIE Chromaticity Coordinates**



N-B DAP: x=0.486, y=0.465 N-Al DAP: x=0.137, y=0.085

## Relationship between Luminous Efficacy and CRI



Nordic Energy

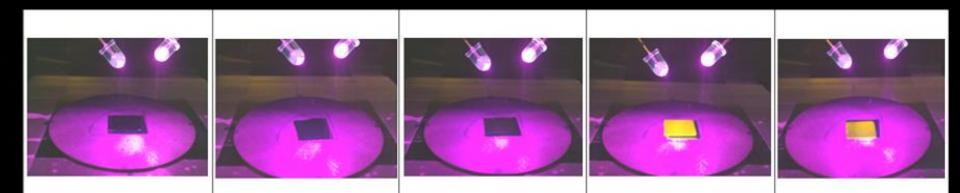
Northern European Innovative Energy Research Programme N-INNER

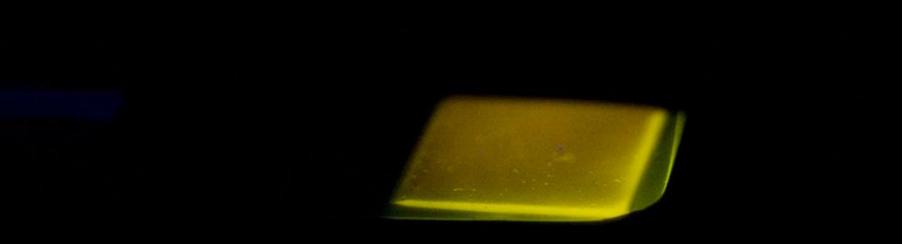
> The Swedish Energy Agency Danish Council for Strategic Research Projektträger Jülich in Germany Research Council of Norway

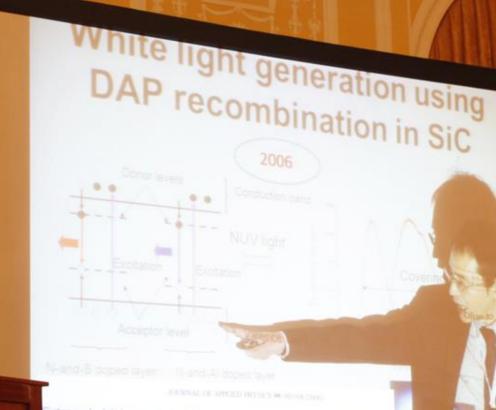
Ångpanneföreningen Research Foundation Richerts Foundation Swedish Research Council Bundesministerium für Bildung und Forschung Danish council of research

Japan Society for the Promotion of Science Department of the New Energy and Industrial Technology Development Organization (NEDO)









Extremely high quantum efficiency of donor-acceptor-pair emission in N-and-B-doped 6H-SiC

 Wattripatria, Y. I. Maleta, Y. Nabartuta, M. Iwaya, H. Attanto, and I. Akasaki. Faculty of Kolomic and Behmings and Sum Facure Medie Construm. 1 NII Department's Departmenta, Nauron 2018, 2017. June Adv. Mat. Lett. 2012, 3(3), 175-176

**ADVANCED MATERIALS Letters** 

www.vbripress.com, www.amlett.com, DOI: 10.5185/amlett.2012.7002

Published online by the VBRI Press in 2012

#### Perspectives of fluorescent and cubic silicon carbide

(a) C. C. Stranger, J. C. Stranger, M. K. Stranger, M. K. Stranger, M. S. Stranger, and S. S. Stranger, M. S. Stranger, S. Stranger, S. S. Stranger, S. S. Stranger, S. S. Stranger, S. Stra Weight of these heads and the standing standing to be full and specify and standing to the standing of the standing standing of the standing o Destructions of these standards and relations is four-standards for the interval (interval) and the standard in the standard interval (interval) (interval) (interval) (interval) (interval) on the standard (interval) ( Ballanger advantue and another strate if advances again, contraints on the chart of theorem Eq. (but, who of the strategies, respire, the strategies of the strategies again of the strategies of the strategie

sity, Department of Physics, Chemistry and Biology, Linköping 58131, Sweden

uthor. Tel: (+46) 1328-5708; Fax: (+46) 1314-9403; E-mail: mikael.syvajarvi@ifm.liu.se

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med Vetenskapsnyheter, Vetandets värld, Vetenskapsradions veckomagasin

#ADIDIPORTEN

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EANALIS

#### Mindag 18 Februari 2009

#### Ny typ av lysdiod kan ersätta glödlampan

toart släcks glödlampan snart für gott, Inom tre år ska lamporna vara borta från marknaden. Det har EU beslutat, Orsaken är att glödlamperna är ineffektiva och EU vill minaka elavukudaingen. På Linköpings oniversitet





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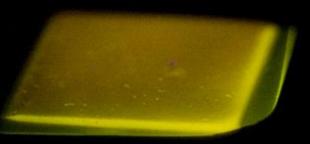


# 2010 – 2012/2013







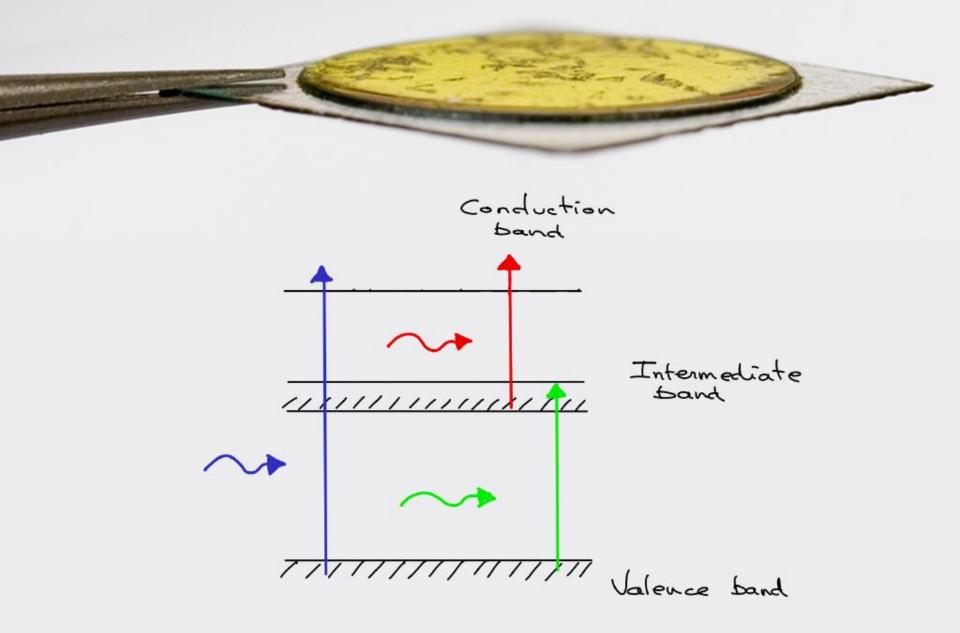


# NETWORK

# what we gained



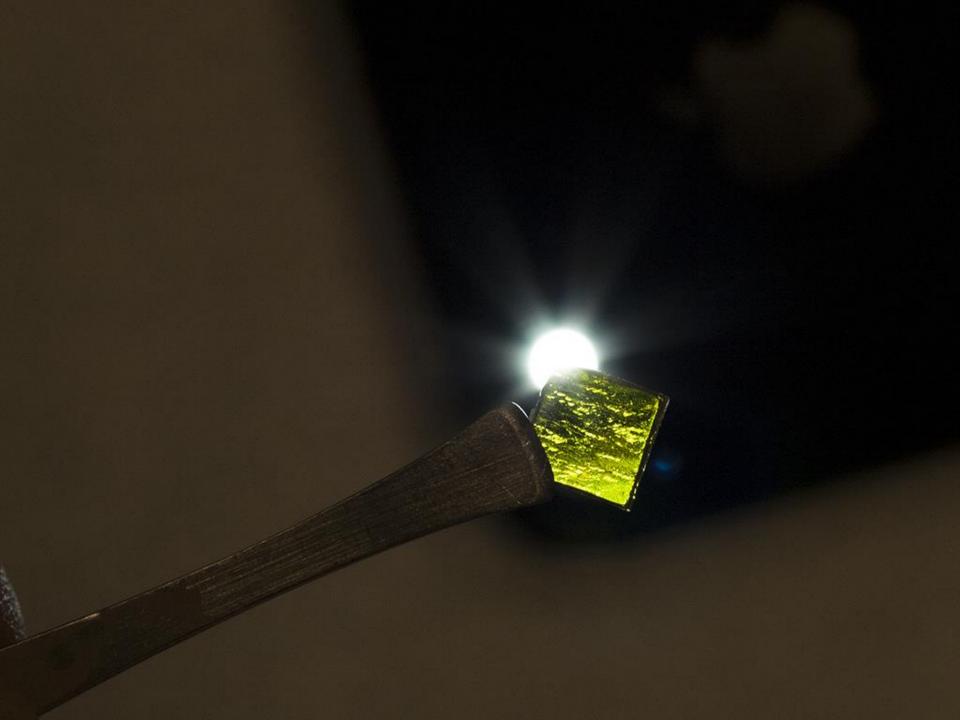
### Another new idea: silicon carbide as solar cell material





FULL Proposal for a new COST Action TITLE: PHOTOVOLTAIC: NEW ALTERNATIVES AND INNOVATIVE MATERIALS

6



# THANK YOU

- Chiu
- ides-Garcia
- Avouris
- u Xia
- imitrakopoulos
- g Sung nnon
- mp
- inding

# Thank you for the invitation and your kind attention!

# Nordic research

## NORLED

- Northern Light Emitting Diode Initiative
- 2010-2012

#### NORLED

The NORLED project develop an innovative and industrially feasible white LED technology for general lighting. The white LED structure is free of phosphor and has a highly efficient luminescence with a comfortable light quality to the human eye. The project consortium is composed of partners from Sweden, Denmark, Germany and Norway. Multidisciplinary (technical, social, economic) scientists are gathered together with representatives from the industry.

Project duration is Jan 1, 2010 - Dec 31, 2012.



#### NEWS

Jan 1, 2010 - NORLED project is officially started!

# Northern Light Emitting diode initiative N-Inner (ii) project

- Nordic Energy Research managing call
- 11 partners
- 4 countries
  - Sweden,
  - Germany
  - Denmark
  - Norway

#### SWEDEN:

Linköping University:

Dr. Mikael Syväjärvi, PhD student Valdas Jokubavicius (Material science crystal growth - FSGP development) Dr. Mats Bladh (new lighting solutions and their social tendencies) Dr. Mats Söderström (energy systems)

Jönköping University:

Prof. Nils Svendenius (room lighting design)

Royal Institute of Technology:

Dr. Margareta Linnarsson (material doping evaluation)

Optoga AB:

Dr. Marcus Björkman (LED armature)

Trans Atlantic Technology AB:

MSc Johan Ekman (industrial application and production technology)

#### NORWAY:

University of Oslo:

Dr. Harold Wilhite (environmental change and sustainable energy)

#### DENMARK:

Technical University of Denmark:

Dr. Haiyan Ou, new PhD student (LED and optical characterization)

#### GERMANY:

University of Erlangen:

Prof. Dr. Peter Wellman, PhD student MSc Michl Kaiser (fundamental SiC crystal growth and doping) Prof. Dr. Erdmann Spiecker, one postdoc/PhD student (structural properties of doped crystals)



# VETENSKAPSRADION

med Vetenskapsnyheter, Vetandets värld, Vetenskapsradions veckomagasin

Möndag 18 Februari 2009

att glödlamperna är

På Linköpings universitet

pågår just nu forskning

kring en lysdied som ska ersätta glödlampan.

#### Ny typ av lysdiod kan ersätta glödlampan

Mandella Variat



Designet Milligal Bandsteret Conditioning a subsequent all and

Hikael Synaparel, Linkopings universite?

104



Rositsa Yakimova och Mikael Syväjärvi vid Linköpings universitet har utvecklat ett nytt material för lysdioder. 46 miljoner ska sätta fart på projektet. Foto: Stefan Jerrevång

Tipsa Skriv ut Större text

#### Linköpingsljus lockar japaner

Av: Ulla Karlsson-Ottosson Publicerad 12 maj 2010 00:00 10 kommentarer

Högeffektiva lysdioder som sprider ett varmt vitt ljus. Linköpingsforskare får nu draghjälp av Japan för att ta fram en bra ersättare till glödlampan.



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+11

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12.54

LINK OPING, Publicerad III 14:37, 14 feb 2005 Skriv ut.

### Nytt ljus bortom glödlampan



Tearrot som Mikael Syväsansi tilbör samarbetar med ett japanskt hordkarlag. - Vi är i prinzig ernamma i världen om värt sätt ta fram kiselkarbid, säger han. Det borde innebär ett förspräng för Uniköping när dan nya luadiadan sã amäningam kan börja nàrma sig entepreduktion, Peanar han...

# **Overview of project participants**

#### SWEDEN:

#### Linköping University:

Dr. Mikael Syväjärvi (Material science crystal growth - FSGP development)

Dr. Mats Bladh (new lighting solutions and their social tendencies)

Dr. Mats Söderström (energy systems)

Jönköping University:

Prof. Nils Svendenius (room lighting design)

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Dr. Haiyan Ou (LED and optical characterization)

#### GERMANY:

University of Erlangen:

Prof. Dr. Peter Wellman (fundamental SiC crystal growth and doping) Prof. Dr. Erdmann Spiecker (structural properties of doped crystals)

#### 11 partners But mainly 4 active (with PhD students)

#### These 4 now continue network

# Project budget, total and with an overview of external funding from other sources

- N-Inner (The Swedish Energy Agency, Danish Council for Strategic Research, Projektträger Jülich in Germany, Research Council of Norway) 700'000 EUR
- Swedish Research Council 2.4 MSEK
- Ångpanneföreningen Research Foundation 0.5 MSEK
- Vinnmer/Vinnova 2.4 MSEK
- NEDO (Japan) 5.6 MSEK
- Bundesministerium f
  ür Bildung und Forschung (Germany) 390.000 EUR
- Danish council of research 2.0 M DKK

# Project progress and possible deviations

- Explore a new scientific field
  - Make light emitting material, study it
  - 3 invited talks at conferences
- Great progress
  - Two papers describing research area included in Physica Scripta Highlights of 2012

From Emma Watkins Subject Request for permission to use your image from Physica Scripta - please respond To Me



Dear Dr M Syväjärvi,

I am pleased to inform you that your paper 'Fluorescent SiC as a new material for white LEDs' has been selected to be included in the Physica Scripta Highlights of 2012. This collection celebrates the most influential research published in the journal from the last 12 months, and will be promoted in print and online for the next 12 months.

# Scientific findings and uniqueness of the project

- Demonstrated light emission from a new material and how physics can be understood
- Implemented growth methods and characterization methods to make and study the material

• Not explored by any other group world wide!

# Networks, co-operations, seminars and mobility.

### International cooperation

- Japanese project on LED (Meijo University)
  - Continues after NORLED
- Vilnius University

### Organized symposiums

- Energitinget 2010
- E-MRS 2011
- E-MRS 2013

### Mobility

By PhD students, postdocs, senior

# Mobility / visits

- At LiU
  - ERLANGEN 2 weeks by PhD student, 6 months by 2
     Erasmus diploma thesis student (joint thesis ERL and LiU)
- Several short visits LiU, Erlangen, DTU
- At Meijo
  - DTU, 3 month by PhD student, 3 months by senior
  - LiU, 2 weeks by postdoc
- At Vilnius University
  - Short visits

# NORLED workshop

• Arranged Nov 2012

PhD students and postdocs

Michl Kaiser, Philip Hens, Valdas Jokubavicius, Ahmed Fadi, Daisuke Iida, Yiyu Ou, Jianwu Sun

Lunch to lunch workshop

Presentations of own topics and new ideas

# Results: Phd degrees and academic publications

- Three PhD students
  - Thesis 2013-2014
  - 7xMaster theses, 6xBachelor theses

- Academic publications:
  - 2010 (1 conference, 1 journal)
  - 2011 (8 conference, 4 journal)
  - 2012 (15 conference, 14 journal)

# Other publications / information activities (web, social media, television, daily press et cetera)

- Popular scientific presentations
  - Kungliga Ingenjörsvetenskapsakademien 100414
     "Smart belysning hur bra kan lysdioder bli?",
  - Fysikstudenter, Linköping 101027 "Framtidens material –grafen och vita lysdioder"
  - Oslo University 110408 "Development of phosphor free white LED for general lighting"
  - Länsstudiedagen, Linköping University 111013
     "Nobelpriset i fysik 2010 (grafen) och vita lysdioder

# Media

Elektroniktidningen 100118, Ny Teknik 100118, Swedish Radio Vetenskapsnyheter 100118, Ny Teknik 100512, Ny Teknik 100823, Ny Teknik 101005, Östnytt Television 101008, Swedish Television Östergötland 110518, Norrköpings Tidningar 110518, Swedish Radio Östergötland 110519, Ny Teknik 110928, Östgöta Correspondenten 111001, Swedish Radio Vetenskapsnyheter 120306, Ny Teknik 120306, Elektroniktidningen 120306, Swedish Radio Vetandets Värld 120307, Semiconductor Today 120309, Compund Semiconductor 120319, Ny Teknik 120619, Semiconductor Today 120620, Elektroniktidningen 120628, Swedish Television Östergötland 120703

# Research

Research is cancelled due to lack of funding

what did the n-inner call do for the initiation of collaboration, research area and network, how will it move forward?

### • A great network

N-Inner funding made collaboration and initial network possible

• We had NOTHING before

Network would have not existed without NORLED No new funding yet

- Applied ITN (failed) and COST application (submitted) for collaboration
- New idea:

Photovoltaic silicon carbide research area