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

Fluorescent silicon carbide for white LEDs
white LEDs
Phosphor conversion
3.05 Sublimation Epitaxial Growth of Hexagonal and Cubic SiC

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

© 2011 Elsevier B.V. All rights reserved.
A Note on Carborundum.

To the Editors of Electrical World:

Sirs:—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.

White light generation using DAP recombination in SiC
White light generation using silicon carbide

- Broad wavelength outputs from N-B and N-Al transitions due to several energy levels

Covering blue to red
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

Requirement for lighting applications

- Blue+YAG (Low Ra)
- Blue+RG (High Ra)
- Blue+Amber (Warm white)
- f-SiC/NUV (Warm/pure white & High Ra)
- NUV+RGB (High Ra)

Legend:
○ Research level
△ Production level
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)
White light generation using DAP recombination in SiC

2006

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

S. Kamisaka, T. Maide, Y. Nakamura, M. Ikeda, H. Itahara, and I. Akasaki
Faculty of Science and Technology and Nano Factory, Meijo University, 1-500, Tempaku-ku, Nagoya 468-8502, Japan
Perspectives of fluorescent and cubic silicon carbide

M. Nyholm, Department of Physics, Chemistry and Biology, Linköping 58131, Sweden
Author. Tel: (+46) 1328-5708; Fax: (+46) 1314-9403; E-mail: mikael.sylvjarsven@ifm.liu.se

2012 and Accepted: 03 June 2012
Perspectives of fluorescent and cubic silicon carbide

Mikael Syvajarvi

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

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

2012 and Accepted: 03 June 2012
2010 – 2012/2013
Another new idea: silicon carbide as solar cell material
FULL Proposal for a new COST Action

TITLE: PHOTOVOLTAIC: NEW ALTERNATIVES AND INNOVATIVE MATERIALS
THANK YOU
Thank you for the invitation and your kind attention!
Nordic research

NORLED

- Northern Light Emitting Diode Initiative
- 2010-2012

The NORLED project develops 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)
- Optega 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)
Ny typ av lysdiod kan ersätta glödlampan


Rositsa Yakimova och Mikhail Syvakani vid Linköpings universitet har utvecklat ett nytt materia för lysdioder. 46 miljoner svar sätta fart på projektet. Foto: Stefan Jerreväng

Nytt ljus bortom glödlampan

Linköpingsljus lockar japener

Av Ulla Karlsson-Oktosson

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.
Overview of project participants

11 partners
But mainly 4 active (with PhD students)
These 4 now continue network

SWEDEN:
Linköping University:
Dr. Mikael Syvajärvi (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 Svendénius (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 Willhite (environmental change and sustainable energy)

DENMARK:
Technical University of Denmark:
Dr. Haiyan Oue (LED and optical characterization)

GERMANY:
University of Erlangen:
Prof. Dr. Peter Wellman (fundamental SiC crystal growth and doping)
Prof. Dr. Erdmann Speecker (structural properties of doped crystals)
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 für 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

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

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