The 3rd European-Asian Workshop on Light-Emitting Diodes

March 5-6, 2015

Copenhagen, Denmark

Organizers:

Haiyan Ou; Yiyu Ou

DTU Fotonik, Technical University of Denmark

Preface

The 3rd European-Asian Workshop on Light-Emitting Diodes aims at promoting scientific exchanges mainly among China, Japan and Denmark within material growth, device and application of LEDs. Three Japanese scientists won the Nobel Prize in physics 2014 due to their significant contribution to the invention of blue LEDs and high impact to the society of the invention. China is undergoing a rapid economic development and has paid more and more attention to sustainable and green technologies in many sectors. Denmark has been for a long time considering the sustainable and environmental issues when developing new technologies. As energy-efficient new light source, this workshop also provides a platform for inspirations and collaborations on research and development of LEDs.

The 1.5-day workshop is financially supported by the 2013 strategic research award for research with great innovation potential from the Danish council for the strategic research.

Program

Chair: Haiyan Ou

Place: Room S09, building 101, Technical University of Denmark
Anker Engelunds Vej 1, DK-2800, Lyngby

Day 1: March 5th, 2015

09:00~09:20	Opening address *Lars-Ulrik Aaen Andersen, Technical University of Denmark, Denmark*
09:20~09:50	Defect analysis and its influence on luminescence properties in fluorescent SiC *Satoshi Kamiyama, Meijo University, Japan*
09:50~10:20	Fabrication of InGaN/GaN nanopillar light-emitting diode arrays *Yiyu Ou, Technical University of Denmark, Denmark*
10:20~11:00	Coffee break
11:00~11:30	High In composition InGaN-based light-emitting diodes grown by MOVPE *Daisuke Iida, Tokyo University of Science, Japan*
11:30~12:00	Fundamental issues for solid state lighting: high quality growth, efficiency droop and p-type doping *Zhiqiang Liu, Xiaoyan Yi, and Meng Liang, Institute of Semiconductors, Chinese Academy of Science, China*
12:00~14:00	Lunch
14:00~14:30	Diode laser lighting technology *Paul Michael Petersen, Technical University of Denmark, Denmark*
14:30~15:00	Dielectric coating and surface plasmon enhancement of multi-color quantum-well structures *Ahmed Fadil, Technical University of Denmark, Denmark*
15:00~15:30	Coffee break
15:30~16:00	Extremely low-resistivity and high-carrier-concentration Si-doped AlGaN with low AlN molar fraction for improvement of wall plug efficiency of nitride-based LED *Motoaki Iwaya, Meijo University, Japan*
16:00~16:30	Fabrication of nano-scale patterned sapphire substrate for GaN based nanopillar LED *Stanley Lim, Technical University of Denmark, Denmark*

18:30	Dinner

Day 2: March 6th, 2015

09:00~09:30	Transmittance enhancement in 6H-SiC with nanocone structures *Weifang Lu, Technical University of Denmark, Denmark*
09:30~10:00	Optical design for multi – colored LED lighting systems for museum lighting application *Maumita Chakrabarti, Technical University of Denmark, Denmark*
10:00~10:30	Coffee break
10:30~11:00	The PV LED Engine – a new generation of intelligent solar powered LED lighting *Peter Behrensdorff Poulsen, Technical University of Denmark, Denmark*
11:00~11:30	Development of LED Light Sources for Improved Visualization of Veins: a statistical approach *Aikaterini Argyraki, Technical University of Denmark, Denmark*
11:30~11:50	Closing address *Haiyan Ou, Technical University of Denmark, Denmark*
12:00~14:00	Lunch

Content

Defect analysis and its influence on luminescence properties in fluorescent SiC

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Abstract— **Generation of stacking faults and neighboring BPDs are thought to be the dominant non-radiative recombination centers to reduce the IQE in fluorescent SiC.**

Keywords— SiC; doping; defect; internal quantum efficiency

I. INTRODUCTION

A wide-bandgap semiconductor, 6H-SiC is a promising rare-earth-free fluorescent material for the emission of visible light, although it is an indirect bandgap semiconductor [1]. The fluorescent SiC (f-SiC), which contains two donor-acceptor-pairs (DAPs) of N-B and N-Al, can create high quality white light covering a whole visible spectral range [2,3]. However, there are some kinds of nonradiative recombination centers, such as $Z_{1/2}$ states, dislocations, surface states and stacking faults. Auger recombination is also an obstacle of highly efficient DAP recombination. Figure 1 shows a band diagram of the f-SiC, where such defect-related transitions are involved. Not only the non-radiative recombination but also light absorption losses should be reduced. In this talk, study on the defect analysis and its influence on the luminescence properties in the f-SiC are discussed.

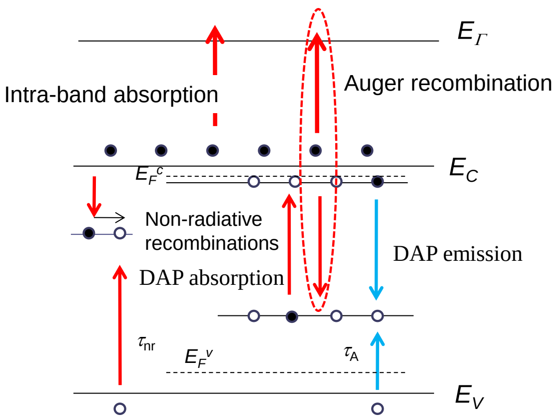

Fig. 1. Band diagram of f-SiC.

II. EXPERIMENTAL AND DISCUSSIONS

Figures 2 shows IQE as a function of BPD density. The BPD densities were measured from the etch pit counting in KOH-etched samples. The IQE is clearly dependent on the BPD density. The BPDs and the stacking faults are almost generated near the interface of seed substrate and the epilayer, and the BPDs are propagating on the stacking faults. Such defects are thought to be caused under the tensile stress accumulation in highly doped epilayer, because of the lattice constant reduction by B doping. In case that the epilayer thickness is less than a certain critical thickness, the defect formation is not so significant. Stress control may be indispensable to improve the IQE by increase of doping concentrations.

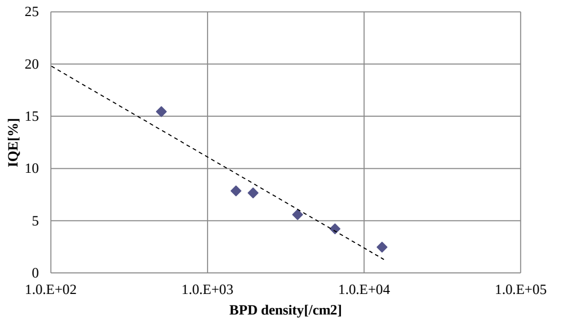

Fig. 2. Internal quantum efficiency (IQE) as a function of basal plane dislocation (BPD) density

III. SUMMARY

Generation of stacking faults and neighboring BPDs are thought to be the dominant non-radiative recombination centers to reduce the IQE. They are caused by the relaxation of tensile stress in the epilayers. The stress control in the epilayer must be necessary to improve the optical performance of f-SiC.

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Fabrication of InGaN/GaN nanopillar light-emitting diode arrays

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***Abstract*— Nanopillar InGaN/GaN green light-emitting diode arrays were fabricated by using self-assembled nanopatterning and dry etching process. Both internal and external quantum efficiency were increased due to strain relaxation and enhanced light extraction.**

Keywords*— *light-emitting diode; nanopillar LED; QCSE

I. INTRODUCTION

In recent years, nitride-based semiconductors have been widely explored for their applications in light-emitting diodes (LEDs) and enormous progress has been achieved including the commercialization of blue LEDs [1]. In order to replace the conventional light sources, LEDs with further improved efficiency are expected. One fundamental limit in LEDs is the low internal quantum efficiency (IQE) caused by the large spontaneous polarization and piezoelectric field due to the large internal strain in multiple quantum wells, known as the quantum confined Stark effect (QCSE) [2]. The other limit is the low light extraction efficiency (LEE) caused by the total internal reflection at different material interfaces.

In this work, nanopillar array has been fabricated on InGaN/GaN green LEDs. Both IQE and LEE were enhanced significantly.

II. FABRICATION AND CHARACTERIZATION

To fabricate the nanopillar structure, a thin SiO_2 interlayer was first deposited on a planar InGaN/GaN green LED epiwafer, followed by the deposition of a thin Au film. The sample was subjected to rapid thermal processing to form self-assembled Au nanoparticles. The nanopattern was transferred from Au nanoparticles to SiO_2 film by reactive-ion etching and further to LED by inductively coupled plasma etching. Nanopillar LED structure with a height of 580 nm was formed and treated by HCl solution to cure the etching damages on the structure surface.

The nanopillar LED and a planar reference LED were then characterized by photoluminescence (PL) measurement and the results were demonstrated in Figure 1. It is seen that the luminescence of nanopillar LED was enhanced by a factor of 4.08. Such considerable enhancement consists of both increased IQE and LEE. The IQE enhancement was caused by a strain relaxation and reduced QCSE. It is confirmed by the blue-shift of the PL emission peak.

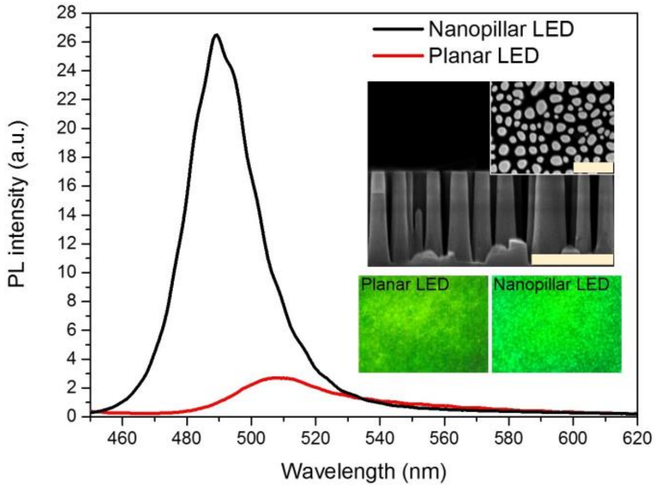

Fig. 1. PL intensity spectra of planar and nanopillar LEDs (inset: upper is cross-sectional and top-view SEM images of the nanopillar structure, both scale bars represent 500 nm; below is microscope photoluminescence images of the two LED samples).

The LEE was also enhanced due to the increased scattering and reduced reflection at the sidewall of the nanopillar structure.

III. SUMMARY

A luminescence enhancement with a factor of 4.08 was achieved by fabricating nanopillar structure on green LED. The promising results suggest that nanopillar LED fabricated by this method is an effective way to enhance the emission efficiency of green LEDs.

ACKNOWLEDGMENT

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High In composition InGaN-based light-emitting diodes grown by MOVPE

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***Abstract*— We developed the longer wavelength of InGaN-based light-emitting diodes grown on c-plane sapphire substrate by metalorganic vapor-phase epitaxy. Optical properties were enhanced by optimization of growth condition.**

***Keywords*— InGaN, light-emitting diodes, MOVPE, wide bandgap semiconductors**

I. INTRODUCTION

Group-III- nitride-based light-emitting diodes (LEDs) have been commercialized as a results of outstanding breakthroughs[1-3]. In particular, the external quantum efficiency of blue LEDs has reached approximately 83%[4]. InGaN-based LEDs appear to be excellent candidate in the solid-state platform for next generation illumination. However, the performance of these LEDs in the longer wavelength regions, such as green, yellow and red regions is still unsatisfactory. The longer wavelength LEDs are also a major focus in the research of group-III-nitride-based LEDs. However, typical InGaN (700~800^{o}C) growth temperature should be lower than that of GaN (~1000^{o}C). Previously, our group has been investigated to improve the crystalline quality of InGaN by computation simulation for the InGaN growth dynamics. It can be obtained the high In composition InGaN-based LEDs with a peak emission wavelength of 740 nm by modified reactor[5]. In this work, we have investigated the optimization of growth condition and structure.

II. EXPERIMENTAL AND RESULTS

All the samples were grown by metalorganic vapor-phase epitaxy in a single wafer horizontal reactor. The total pressure was 100 kPa during growth. We fabricated a longer wavelength LEDs with highly In composition InGaN multiple quantum well (MQW) grown on *c*-plane sapphire substrate. The active layer consisted of 3 periods of InGaN/AlN/(Al)GaN MQWs which is controlled strain structure. The QWs and AlN interlayer were grown at 740^{o}C, the (Al)GaN barrier layer was grown at 850^{o}C. With increasing barrier growth temperature, it could be improved the crystalline quality of InGaN QWs. First, we estimated the internal quantum efficiency (IQE) with various excitation power densities by cryogenic temperature photoluminescence (PL). The PL setup consist of InGaN laser (λ = 405 nm) which could turn the excitation power density from 1.1 to 113 W/cm^2. The IQE was defined by integrated PL intensity ratio at room and cryogenic temperatures. The IQE was 11% at 113 W/cm^2. Figure 1 shows the electroluminescence (EL) spectrum of amber LED at 20 mA. It found that the amber LED has two emission peaks which are from InGaN QWs and phase separation component in that of InGaN. We suggest that the phase separated InGaN was suppressed the efficiency of InGaN-based LEDs in the longer emission wavelength region. Therefore, for the enhancement efficiency of these LEDs, it should be reduced the phase separated InGaN by optimizing growth condition.

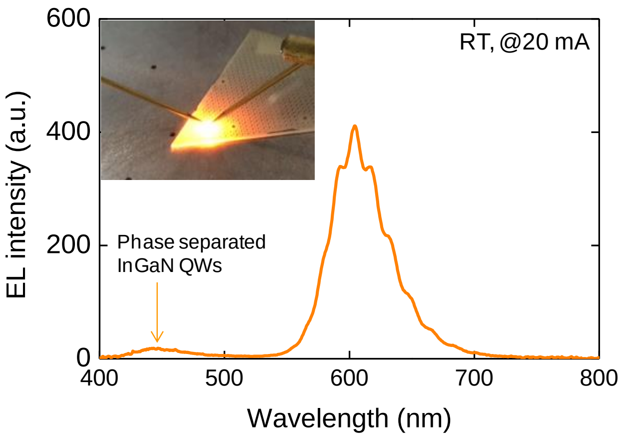

Fig. 1. EL spectrum of InGaN-based LED. Inset is shown EL driven.

III. SUMMARY

We have developed the longer wavelength InGaN-based LEDs with optimization of growth condition and structure. Increasing growth temperature of InGaN should be important to improve the crystalline quality. We achieved that the IQE of amber LED with the peak wavelength of 600 nm was 11% at 113 W/cm^2 by PL measurement. We found that the EL spectrum appear blue emission from phase separated InGaN QWs.

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Fundamental Issues for Solid State Lighting: High Quality Growth, Efficiency Droop and p-type doping

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***Abstract*— The main concerns of this work are some fundamental issues, which impede the further development of solid state lighting, including high quality GaN Growth, droop effect and p-type doping for wide band gad materials.**

***Keywords*—GaN Growth; droop effect; p-type doping;**

I. INTRODUCTION

In this work, The growth process of three-dimensional growth mode (3D) switching to two-dimensional growth mode (2D) is investigated when GaN films are grown on cone-shaped patterned sapphire substrates by metal-organic chemical vapor deposition. The growth condition of the 3D-2D growth process is optimized to reduce the threading dislocation density (TDD). It is found that the condition of the 3D layer is critical. The 3D layer keeps growing under the conditions of low V/III ratio, low temperature, and high pressure until its thickness is comparable to the height of the cone-shaped patterns. Then the 3D layer surrounds the cone-shaped patterns and has inclined side facets and a top (0001) plane. In the following 2D-growth process, inclined side facets coalesce quickly and the interaction of TDs with the side facets causes the TDs to bend over. As a result, the TDD of GaN films can decrease to 1 × 108 cm-2, giving full-width at half maximum values of 211 and 219 arcsec for (002) and (102) omega scans, respectively.

the dislocation-related efficiency droop in InGaN/GaN blue light-emitting diodes (LEDs) was investigated by comparing the external quantum efficiency (EQE) of GaN grown on c-plane sapphire and free-standing GaN substrate over a wide range of operation conditions. The values of A, B, and C coefficients had been iteratively obtained by fitting quantum efficiency in the rate equation model. Analysis revealed that threading dislocation (TD) density was strongly related to the decrease in EQE of InGaN LEDs at elevated currents by introducing a number of acceptor-like levels with the energy EA lying within the band gap.

Furthermore, we propose a novel approach to reduce the ionization energy of acceptors in GaN through Zn-Mg codoping. The characteristics of the defect states and the valence-band maximum (VBM) were investigated via first-principles calculation. Our results indicated that the original VBM of the host GaN could be altered by Zn-Mg codoping, thus improving the p-type dopability. We show that the calculated ionization energy $\varepsilon(0/-)$ of the Zn-Mg acceptor is only 117 meV, which is about 90 meV shallower than that of the isolated Mg acceptor.

II. FIGURES AND TABLES

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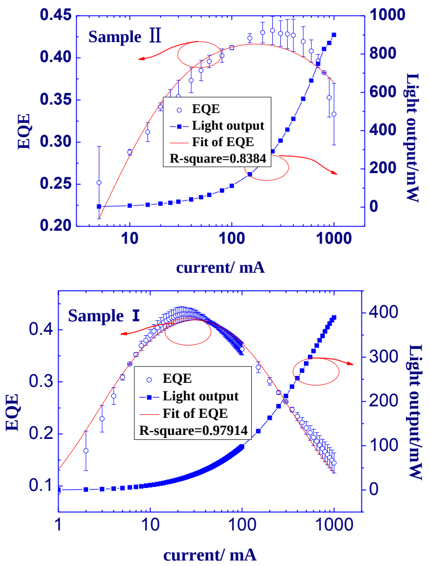

Fig. 1. Quantum efficiency and light output as function in sample A and B. The date points represent the measured results. The solid line on quantum efficiency represents the fitting curve based on carriers rate equation.

III. SUMMARY

In this paper, we report our research work on the 3D-2D growth process when GaN films grow on cone-shaped patterned sapphire substrates (PSS) by metal-organic chemical vapor deposition (MOCVD) to reduce TDDs. Furthermore, some promising methods were proposed to address the issues of efficiency droop and p-type doping. c

Dielectric coating and surface plasmon enhancement of multi-color quantum-well structures

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***Abstract*—We fabricate a multi-colored quantum-well structure as a prototype towards monolithic white light-emitting diodes, and modify the emission intensities of different colors by introducing dielectric and Ag nanoparticle coating.**

***Keywords*— White LED; Surface plasmonics; Ag nanoparticles**

I. INTRODUCTION

The development of white light-emitting diodes (LEDs) has become an important issue for light applications due to their long lifetime, small size, and low power consumption. The creation of white light out of monochromatic visible spectrum emitters can be based on phosphor converted white LEDs (blue+yellow) [1]. However, using phosphor converters complicates the LED process and increases the manufacturing cost; hence a phosphor free approach is desirable. Monolithic phosphor free approaches to achieve white LED have been researched over the past few years using III-nitrides [2-4]. Due to quantum-confined Stark effect the increasing indium composition results in a decreasing emission intensity at longer wavelengths.

We investigate the photoluminescence (PL) of a multi-colored quantum-well light-emitting structure, and demonstrate a simple method to modify and improve the PL emission spectrum using dielectric coatings and self-assembled Ag nanoparticles (NPs).

II. EXPERIMENTS AND RESULTS

A light-emitting structure with three quantum-wells of different In-composition is grown by MOCVD to achieve three different colors as shown in Fig. 1a. The PL spectrum of the as-grown structure is shown in Fig. 1b (dash-black), however, only two peaks are visible at λ_1 = 570 nm and λ_2 = 500 nm. The spectrum shows the total PL collected from both sapphire and GaN side emission, with sapphire side excitation.

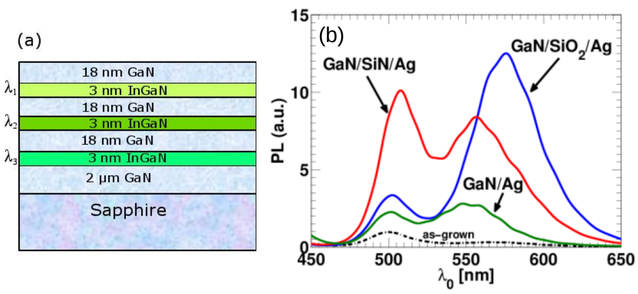

Fig. 1. a) The multiple-color InGaN/GaN QW structure where $\lambda_1 > \lambda_2 > \lambda_3$. b) Total PL spectra of the as-grown QW (black dashed). Comparison is made between 20 nm SiO_2 and SiN thin film together with Ag NP coating.

Fig. 1b shows the effect of introducing Ag NPs on the GaN surface to improve the PL emission (GaN/Ag). The QW with λ_1 is enhanced more than that of λ_2. Enhancements are the result of localized surface plasmon (LSP) coupling with QWs, and this interaction decreases with distance between Ag NP and excitons, therefore a stronger enhancement is obtained for the closest QW with λ_1. This effect equalizes the peak intensities of the two QWs, which is a desirable effect when aiming for monolithic white LEDs.

Forming self-assembled Ag NPs on the dielectric coated samples gives the PL spectra as shown in Fig. 1b. With a dielectric layer of lower refractive index, the scattering efficiency of Ag NPs will be improved resulting in a stronger PL intensity [5]. With SiO_2 the enhancements are seen to occur at long wavelengths, while for SiN a more uniform enhancement is obtained. Integrated PL enhancements by Ag NPs relative the as-grown sample are 3.1, 14.0 and 14.4 for bare GaN, SiO_2 and SiN coated samples, respectively.

III. SUMMARY

In conclusion we have grown a multi-color quantum-well structure to emulate a monolithic white LED, and investigated how the emission peaks can be enhanced and equalized using dielectric coating and Ag NPs. While SiN coating shows a uniform enhancement over the emission wavelength range, SiO_2 coating with Ag NPs shows large enhancement at longer wavelengths. This is a promising method to engineer the emission peaks of different QWs in a monolithic white LED design.

IV. ACKOWLEGDEMENTS

This project was supported by Innovation Fond Denmark.

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Extremely low-resistivity and high-carrier-concentration Si-doped AlGaN with low AlN molar fraction for improvement of wall plug efficiency of nitride-based LED

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***Abstract*— We discovered that Si-doped AlGaN with low AlN molar fraction can be used to realize an external low-resistivity n-layer at room temperature. We confirmed a reduction in the differential resistance of a violet light-emitting diode** by using this n-**AlGaN**

***Keywords*—n-$Al_{0.05}Ga_{0.95}N$, activation energy, resistivity**

1.INTRODUCTION

High-brightness GaInN-based visible light-emitting diodes (LEDs) are presently commercialized worldwide, but from a practical viewpoint, the wall plug efficiency (WPE) of such devices needs improvement. Low-resistivity (ρ) at room temperature (RT) n-type nitride is essential for improvement of the WPE in GaInN-based LEDs.

In this presentation, we discovered that Si-doped AlGaN with low AlN molar fraction can be used to realize an extremely low-ρ n-type layer at RT. Also, the reduction of the series resistance of the LED with a high internal quantum efficiency was possible by using this n-type AlGaN underlying layer. Moreover, we investigated the electrical properties of this extremely low-resistivity and high-carrier-concentration Si-doped AlGaN by variable-temperature Hall effect measurement. We also discussed the activation energy of this Si-doped AlGaN.

2. EXPERIMENTAL RESULT

All samples were grown by metal organic vapor-phase epitaxy. C-plane sapphire was used as a substrate covered with a low-temperature buffer layer. An unintentionally doped ~3-μm-thick GaN layer and a ~1.5-μm-thick Si-doped AlGaN layer or GaN layer were then sequentially grown. AlN molar fraction of AlGaN was controlled ranging from 0.03 to 0.05. We measured the variable-temperature van der Pauw Hall effect to determine ne, mobility (μe), and ρ of each sample. The two-dimensional electron gas at the heterointerface between Al0.05Ga0.95N and GaN was ignored because the sheet resistance of each sample was very low. We also characterized the surface morphology by scanning electron microscopy.

Because ne of Si-doped GaN up to 1.0×10^{19} cm^{-3} can be obtained on a smooth surface, we concluded that the surface of this sample was rough because of excess Si. In contrast, a smooth surface was obtained in AlGaN despite the Si concentration being too high; we were unable to confirm the existence of cracks in all AlGaN samples. We concluded that a smooth surface can be obtained by the addition of AlN even though for a high Si concentration. ne at RT of the Si-doped GaN was unambiguously increased up to $4.0x10^{19}$ cm^{-3}. However, ρ at RT of 2.7×10^{-3} Ωcm with ne at RT of 4.0×10^{19} cm^{-3} was close to saturation because μe at RT rapidly decreased with deteriorating surface roughness. In contrast, ne at RT of AlGaN continued to increase to 10^{19} cm^{-3} and further to $1.4x10^{20}$ cm^{-3}. The minimum ρ at RT in Si-doped AlGaN was 5.9×10^{-4} Ωcm. This ρ at RT is lower than that of GaN with Ge doping. Because 3D growth is suppressed using AlGaN even under high Si concentration, μe at RT of this n-AlGaN did not decrease significantly. This result shows the potential of realizing a low-ρ n-type layer by using AlGaN. Moreover, the activation energies of the Si donors in AlGaN with ne at RT were found to be as low as 12 meV by fitting the experimental result by variable-temperature van der Pauw Hall effect measurement. We also confirmed that activation energy in Si-doped AlGaN is roughly proportional to the negative 1/3 power of Si concentration. We also investigated the violet LED on different Si-doped $Al_{0.05}Ga_{0.95}N$ (n_e : 1.0×10^{19} and 1.6×10^{20} cm^{-3}). We confirmed a significant difference in the I-V curve of each LED. By increasing n_e in $Al_{0.05}Ga_{0.95}N$ from 1.0×10^{19} and 1.6×10^{20} cm^{-3}, we found that the operating voltage of ~1 V at 100 mA current injection was reduced. Moreover, the differential resistance at 100 mA current injection (series resistance) of each LED was reduced from 14 to 7.2 Ω. This reduction in differential resistance can be partially explained by the decrease in the sheet resistance of the n-AlGaN layer.

3. SUMMARY

We discovered that Si-doped n-type AlGaN with extremely low ρ (5.9×10^{-4} Ωcm) can be realized at RT. In contrast, ρ for Si doping of GaN was limited to ~2.5×10^{-3} Ωcm because 3D growth occurs at n_e exceeding ~1.9×10^{19} cm^{-3}. A reduction of the series resistance of the LED with a high internal quantum efficiency was possible by using this underlying layer.

Fabrication of Nano-Scale Patterned Sapphire Substrate for GaN Based Nanopillar LED

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***Abstract*— Nano-scale patterned sapphire substrate (NPSS) introduces advantages over lateral substrates. The fabrication of Inductively Coupled Plasma (ICP) dry etched nanopillar (NP) sapphire has been studied intensively for a wide range of parameters. The large-scale monodomain-ordered and vertically aligned sapphire NPs using Cr as etching mask is presented.**

Keywords*— *Nanoimprint lithography (NIL); Light-Emitting Diode (LED); Nanopillar (NP); Patterned Sapphire Substrate (PSS).

I. INTRODUCTION

Nano-imprint lithography (NIL) is a novel, low-cost and high-throughput manufacturing technology for developing nano-scale features for Light-Emitting Diodes (LED). Currently, the most common commercialized PSS LED is in the micron-scale. Micro-scale PSS can enhance the light extraction efficiency of an LED, but it cannot entirely eliminate the total internal reflection. In addition, PSS also reduces the threading dislocation density, which can improve the internal quantum efficiency.

In this study, fabrication of NPSS is conducted for the purpose of GaN NP Metalorganic Chemical Vapour Deposition (MOCVD) growth. GaN NP together with NPSS can dramatically reduce the dislocation density in the upper part of the GaN NP and relieve the strain induced between the GaN/sapphire interface [1]. The internal quantum efficiency can be increased owing to the non-polar geometry of NPs which eliminates the Quantum Confined Stark Effect (QCSE) [2]. It is expected that the core/shell NP structure in which InGaN/GaN multi-quantum wells (MQWs) grown on the NP sidewall can effectively increase the volume of the active region, which leads to an increase of the total light intensity of the same substrate area. Nonetheless, multi-color emission can be obtained by varying the InGaN/GaN NP dimensions, which is promising to realize low-cost monolithic white light emission by RGB color mixing [2]-[4].

II. RESULTS AND DISCUSSIONS

The fabrication process of NPSS is shown in Fig. 1 step by step. A clean *c*-plane sapphire (Al_2O_3) substrate is spin coated with a 210 nm thick *mr-I7020E* imprint resist. The thickness is controlled by the viscosity and the spinning parameter. An inverse replication of NP features are thermally imprinted into the resist serving as sacrificial material, as it will be washed away after the filling step of a 60 nm thick Cr deposition. The pattern transfer is performed using *Electronic Vision Group* (EVG) NIL and the flexible polymer stamp is provided by *Nanoimprint Lithography Technology ApS (NILT).* Afterwards, the ICP dry etching is performed to create NP arranged in a triangular geometry shown in Fig. 2a and 2b. The height and the base diameter of the NP are 235 nm and 347 nm, respectively. A selectivity of 5 is obtained with an etch rate of 47 nm/min.

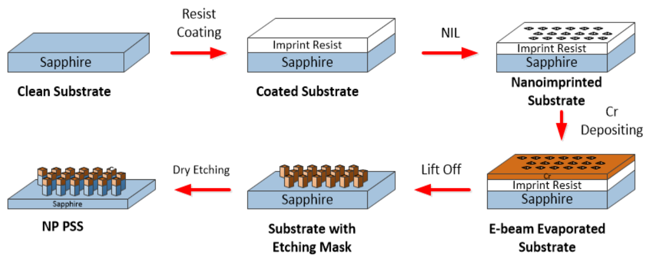

Fig. 1. Fabrication Process of NP PSS

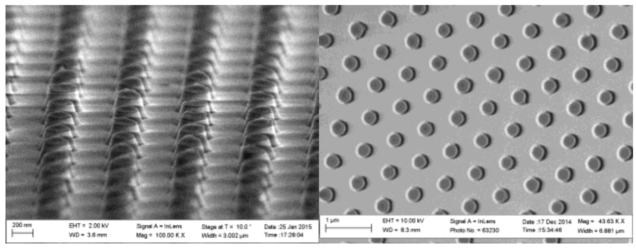

Fig. 2. Scanning Electron Microscopy (SEM) tilted view (left) and plan view (right). images of NPSS with Cr mask. .

III. SUMMARY

With the remarkable NIL technology, superior control in structure, dimension and spatial alignment becomes evident in realizing NPSS. Utilizing NPSS in MOCVD for GaN NP growth allows altering the InGaN/GaN diameter sizes leading to multicolor emission.

IV. FUTURE WORK

Since the 60 nm thick Cr is insufficient for deeper etch, thicker Cr layer is a promising mask material for taller NPs. Thereafter MOCVD growth on NPSS will be performed to create core/shell structures which will be characterized.

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Transmittance enhancement in 6H-SiC with nanocone structures

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***Abstract* — Enhanced transmittance of 6H-SiC with nanocone structures were achieved by using self-assembled Au nanoparticles as etching mask. HF passivation process of nanocone structures was investigated to further improve the transmittance. The max transmittance of structured SiC is significantly improved by 10%.**

Keywords—nanocone; transmittance; HF passivation

I. INTRODUCTION

The light extraction efficiency is one of the most important parameters for high-performance light-emitting diodes, which is usually low due to the refractive index mismatch at the interface of SiC and air[1]. To enhance the extraction efficiency, nanostructures could be implemented at the SiC surface using e-beam lithography[2], nanosphere lithography[3], self-assembled metal nanoparticles[4], or Al thin film[5]. But the surface nanostructures also lead to the enhanced recombination rate due to surface defects and dangling bond, introduced during the fabrication process. To date, hydrogenation, and deposition of SiO_2, SiNx, Al_2O_3 or TiO_2 are effective ways to improve the surface passivation[6]. In this work, nanocone structures on 6H-SiC were achieved by self-assembled Au nanoparticles. We used 5% HF solution to clean and passivate the surface.

II. RESULTS AND DISCUSSIONS

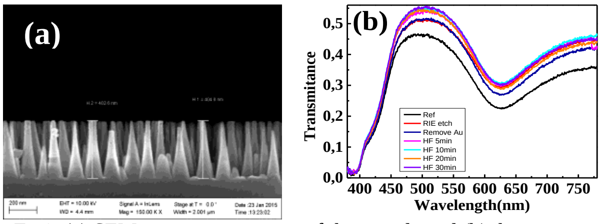

Fig1. (a) SEM cross-section view of the sample and (b) the transmittance curves of the sample after different process.

To improve the uniformity of Au nanoparticles, 20nm SiO_2 layer were deposited on the surface of original 6H-SiC samples. Then, a 6nm Au film layer was deposited on the surface. After treated by rapid thermal annealing at 650 ℃ for 3min, Au nanoparticles were formed. The nanocone structures were fabricated by utilizing RIE etching for 5 min, followed by 15min oxygen plasma cleaning to remove the residual polymer. The residual Au was removed by iodine based solution. The samples were passivated for different time (5min, 10min, 20min and 30min) to improve transmittance. It is found that the nanocone structures are approximately 400nm high and 100nm wide, as shown in Fig.1 (a). Fig1 (b) shows the transmittance curves of the sample after different process, which was measured by a calibrated goniometer system. The transmittance of nanocone structured SiC was enhanced by 6%. After HF passivation for 30min, the transmittance was improved by 10 %.

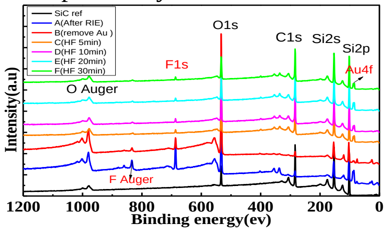

Fig2.XPS survey scans before and after RIE etching, removing Au, HF etching for different time.

The analysis of the surface was carried out with XPS using Al $K\alpha$ radiation with energy resolution of 0.1eV. The corresponding O1s peak was refer to nature oxidation layer of nanocone surface in room temperature as shown in Fig2. It is apparent that RIE processing generated fluoride contamination on the structures, which was practically removed by the oxygen plasma cleaning and HF solution. However, the residual Au couldn ť be cleared away after oxygen plasma process, which may suppress the enhancement of transmittance.

III. SUMMARY

In conclusion, we have shown that the nanocone structures created by using Au particles as etching mask, give rise to the enhancement of transmittance. The HF passivation process was introduced to further improve the light extraction.

ACKNOWLEDGMENT

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Optical design for multi – colored LED lighting systems for museum lighting application

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***Abstract*— we have designed a ray traced model of a new lighting system to provide tuneable low color temperature white light with high color rendering and high angular color homogeneity for the museum application. (Max. 35 words)**

Keywords*— *Colour mixing, LEDs, colour homogeneity, optical ray tracing, dynamic CCT (Max 3 to 5 words)

I. INTRODUCTION

To present and preserve the priceless artefacts, museum lighting system requires special illumination system. Basically it demands low correlated color temperature (CCT) to illuminate objects like gold with high color rendering index (CRI) and good color uniformity for presentation and minimized infrared and ultraviolet radiation for preservation [1]. In this article we investigate the lighting system by ray traced model at the Royal Danish collections where the rare historical artefacts along with crown jewels are preserved in secured display cases for the exhibition at Rosenborg Castle in Copenhagen, Denmark. Earlier the display cases were provided by the 5 W incandescent festoon lamps which are now replaced by our new multi – colored lighting system [2][3]. We are interested in low CCT to obtain the desired visual appearance of the golden artefacts.

II. FIGURES AND TABLES

The article describes the LED optical system which is constructed from one diffuser, a printed circuit board (PCB) with three different colored LEDs.

Figure 1: **Golden artefacts illuminated by multi-colored LED lighting system at the display case in Rosenborg Castle**

Figure **1** shows the display cases where the artefacts are illuminated by our lighting system which can be dynamically tuned from 2000 K to 2400 K with high CRI and low D_{uv}.

III. SUMMARY

The new ray traced model and the numerical simulation have been developed for museum lighting application which is especially illuminates the objects that require low blue content in the light or to render red strongly. The system is based on cyan and deep red LEDs to adjust the spectral power distribution (SPD) of a warm white LED. The optical system is having dynamic CCT ranging from 2000 K to 2400 K with low D_{uv} values and high CRIs (R_9 and R_a). The system shows Ra 97 and R_9 92 in 2000 K. Due to geometrical design, the final output can have symmetric light distribution which provides high color uniformity in the angular space. In future we can use this system as a tool of any number of colored or white LEDs mixing system.

ACKNOWLEDGMENT

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The PV LED Engine – a new generation of intelligent solar powered LED lighting

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***Abstract*— A barrier for exploiting use of standalone solar lighting for the urban environment seem to be lack of knowledge and lack of available tools for proper dimensioning and positioning. This work presents such a tool.**

***Keywords*— PV urban lighting, Energy systems, standalone, LED lighting, Light-2-Light**

I. INTRODUCTION

Digging down cables for small electrical applications in the urban environment is extremely expensive due to the high labor cost associated with it. Small stand-alone PV applications powered by 0.5-50 Wp can become very attractive since e.g. in Copenhagen in Denmark the cost of digging down cables in the city is about 1000 $ pr. running meter so the cost savings on the cable digging can easily pay for the solar cells and electronics. The requirements to the products from the municipalities are high so if e.g. the products are for lighting purpose the reliability of the product meeting some specified amount of light is very important. The barrier for exploiting this potential seems to be the lack of knowledge and tools for dimensioning and designing PV applications for the urban environments. The authors investigated the many PV dimensioning tools on the market and found none addressing exactly this issue and in the present project a design and simulation tool for small PV applications for the urban environment has been developed along with characterization facilities able to characterize the individual components of the system: Solar panel, Battery, Electronics and LED/Luminaire.

II. FIGURES AND TABLES

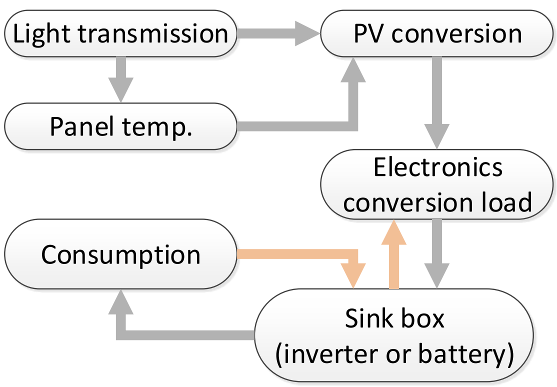

Fig. 1. Block diagram of the PV simulation tool.

Fig. 2. BIKE-LIGHT – solar lighting product for Copenhagen.

III. SUMMARY

A time resolved dimensioning tool schematically shown in figure 1 is developed that uses measured parameters of the individual components in the PV Lighting system for the simulations: PV, Battery, Electronics and LED/Luminaire. The tool uses time resolved solar irradiation data (1 minutes – 60 minutes resolution) separated in diffuse and direct irradiation to calculate the dynamic energy harvesting of the solar panels in the product (eg. BIKE-LIGHT shown in figure 2). An attenuation function based on the measured or simulated shading environment of the product is used to simulate the energy harvesting. Due to the dynamic behavior with different irradiation levels of the PV and lighting levels of the LEDs both the energy harvesting and lighting scheme of the product is modelled time resolved and dynamically to achieve the most lifelike prediction of the product performance to be able to dimension the product perfectly for the given application.

ACKNOWLEDGMENT

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Development of LED Light Sources for Improved Visualization of Veins: a statistical approach

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***Abstract*—The present statistical study investigates the difference of diffuse reflectances between skin and vein (defined as contrast indicator) under different visible wavelengths of a population of 39 adult participants. The purpose of the study is to examine if there is a group of wavelengths-color combinations that could explain most of the variance (of the contrast indicator) in the data set. Moreover the effect of gender and age on the contrast indicator is explored.**

Keywords— Principal component analysis (PCA); LED; vein visualization;

I. INTRODUCTION

The present study is a part of a larger effort concerning improved visualization of biosamples by applying a special illumination source constructed by light emitting diodes (LED)[1]. The current biosample consists of human skin and vein at the wrist region. The fewer wavelengths used for achieving a good contrast (assumed to be equivalent to contrast indicator) the more economic and environmentally friendly the light source is. LED light sources allow almost full control over the wavelengths that are emitted and that opens new possibilities for enhancing the contrast of specimens in a cheap way, by choosing only the wavelength combination that maximizes the contrast for the majority of the population. In order for the concept to make sense, the first thing that needs to be investigated and analyzed is if human vein to skin contrast is similar for a population of people. If at some wavelength combinations the vein-skin contrast varies drastically among a population of people it makes no sense to include these wavelengths in an illumination source designed for optimal visualization of veins. It is known that skin pigmentation of humans varies worldwide, and vein structure (diameter, depth in the skin etc) also differs from person to person. To our knowledge the contrast (in terms of diffuse reflectance) between veins and skin for a population of people, at different combinations of wavelengths or colors, has not previously been reported.

II. RESULTS

Results from a PCA analysis showed that 87.7% of the variance of the data is explained by the first principal component (PC1). All colors have positive and similar sized loadings for PC1 (Fig.1), with yellow contributing most and blue contributing least to this component; explaining 87.7% of the variance. Another interpretation is that the intensity level of the contrast indicator is the parameter that explains most of the variance in the dataset. A high intensity level of the contrast indicator should be perceived as very visible veins under all wavelengths, and are located at high values of PC1 (Fig. 1), and so one could easily identify persons with highly visible veins. 6.2% of the variance of the data is explained by the second principle component (PC2). PC2 involves the distribution (shape of the spectral curve); opposing orange/red to violet/blue. Yellow and green color contribute only very little to PC2. No difference in response or special grouping of the contrast indicator due to gender or age was observed for PC1 or PC2. The explained variance of each of the colors was above 90% in all cases.

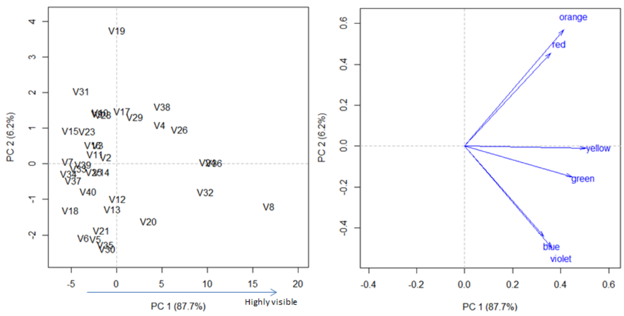

Fig. 1. PCA analysis graph, performed with colors as variables. Points interpreted as bad leverage points were removed from the sample.

III. SUMMARY

It is shown that yellow is the color that contributes most to the variations of vein-skin contrast among a population of 39 samples, while blue is the color which contributes least to the variation of the contrast. Moreover, no grouping of contrast response due to gender or age was observed for any of the visible wavelengths applied.

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Workshop Participant Biographies

Aikaterini Argyraki has a Master of Science in Engineering from DTU (Technical University of Denmark) in Physics and Nanotechnology. After the Master Aikaterini Argyraki worked one year as research assistant on a proof of concept project related to the extraction efficiency of LEDs. In 2013, together with Yiyu Ou and Haiyan Ou from the Diode Laser & LED systems group at DTU-Fotonik, she won the best poster award, at 39th International Conference on Micro and Nano Engineering, presenting a novel nanofabrication method to significantly enhance the luminescence efficiency of current LED devices. Currently Aikaterini Argyraki is working as a PhD student on the development of new light sources for biomedical applications, under the supervision of the Prof. Paul Michael Petersen, Diode Laser&LED systems group, at the Department of Photonics Engineering, DTU.

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Zhiqiang Liu, Ph.D., Professor, semiconductor lighting R & D center, Institute of Semiconductors, Chinese Academy of Sciences, focuses on the area of wide bandgap materials growth, material characterization, the first principle calculation and devices fabrication. He has made pioneering contributions in the development of Solid-State Lighting in China and participated in the many national projects of nitrides field about high power LED structure design and key technology research. He received about $3 million research funding. In the recent 5 years, his research has resulted in more than 50 papers and 30 patents.

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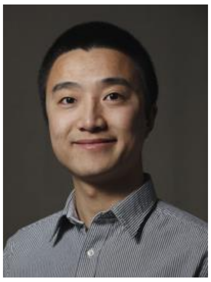

Yiyu Ou received the MSc degree in photonics from Chalmers University of Technology in 2009 and the PhD degree in photonics from Technical University of Denmark in 2013. From 2013, he joined Light Extraction Aps (Denmark) as chief technology officer, where he lead the R&D work to provide novel nano-fabrication solutions. He is currently a post-doc researcher at the Technical University of Denmark. His scientific background is in the areas of materials and devices for light-emitting and energy-saving applications, nano-fabrication technologies and nanophotonics. He has authored and co-authored more than 50 journal and conference papers.

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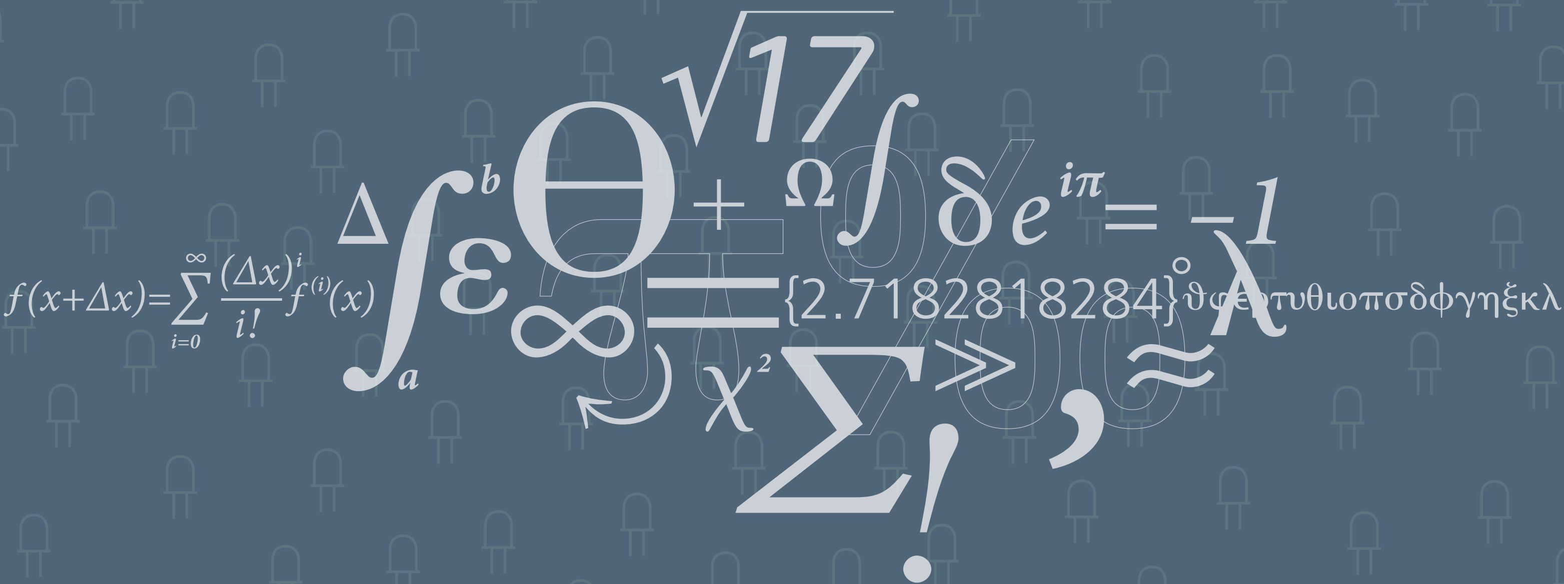
f(x+Δx)=∑ (Δx)^i / i! f^(i)(x)
√17
e^iπ = −1
{2.7182818284}
ϑφεστυθιοπσδφγηξκλ