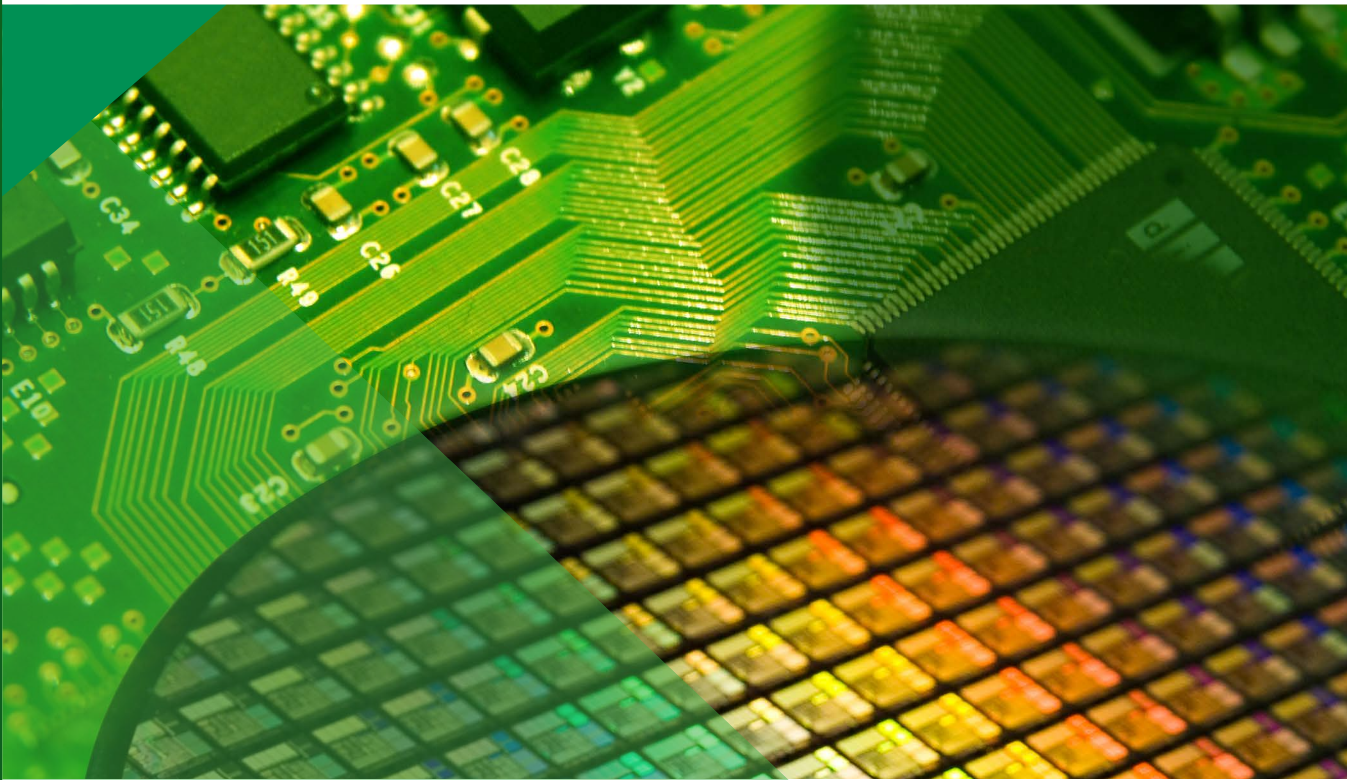
TUM Asia

# Master of Science
# Green Electronics

Technical University of Munich

NANYANG TECHNOLOGICAL UNIVERSITY



## At A Glance

**JOINT DEGREE BY**
Technical University of Munich (TUM)
Nanyang Technological University (NTU)

**TWO-YEAR FULL TIME PROGRAMME**
Coursework in Singapore

**PRACTICAL KNOWLEDGE**
Compulsory Internship & Thesis

**GLOBAL PROSPECTS**
Internationally Recognized Degree

**INTAKE**
August Every Year

**TO APPLY**
Apply online from 15th October at
www.tum-asia.edu.sg

**1** TUM is ranked as the #1 University in Germany+

**1** NTU is ranked #1 in Asia for Engineering++

**1** NTU is ranked #1 in the world for industry income and innovation*

**8** TUM ranked #8 in the Global Employability Survey^

**50** Both TUM & NTU# are in the world's Top 50 Universities

## Technical University of Munich (TUM)

Technical University of Munich (TUM) is one of Europe's leading research universities, with around 500 professors, 10,000 academic and non-academic staff, and more than 40,000 students. Its focus areas are the engineering sciences, natural sciences, life sciences and medicine, reinforced by schools of management and education.

TUM acts as an entrepreneurial university that promotes talents and creates value for society. In that it profits from having strong partners in science and industry. It is represented worldwide with a campus in Singapore as well as offices in Beijing, Brussels, Cairo, Mumbai, and São Paulo.

Nobel Prize winners and inventors such as Rudolf Diesel and Carl von Linde have done research at TUM. In 2006 and 2012 it won recognition as a German "Excellence University." In international rankings, TUM regularly places among the best universities in Germany.

## Nanyang Technological University (NTU)

Inaugurated in 1991, Nanyang Technological University (NTU) has grown to become a full-fledged research university, and is ranked as one of the fastest-rising Asian universities in the world's top 50**. Hailing from more than 70 countries, NTU's 3,800 strong teaching and research staff contribute their dynamic perspectives and years of solid industry experience.

NTU's academic and research programmes, with real-world relevance, have reaped dividends in the form of strong support from major corporations and industry leaders, in terms of both research funding and partnerships as well as global internship opportunities for our students.

As the main Science and Technology university in Singapore, NTU has made substantial contributions to Singapore's drive for research and innovation, with the 2014 Quacquarelli Symonds (QS) ranking NTU at 10th in the World for Electrical & Electronic Engineering.

**As rated by Academic Ranking of World Universities (Shanghai Ranking) 2013, 2017/2018 and QS World University Ranking 2013/2014

# Master of Science
## Green Electronics

TUM Asia's Master of Science in Green Electronics (MSc in GE) equips students with the comprehensive and in-depth knowledge of micro-/nano-fabrication technology, renewable energy, power semiconductors as well as organic semiconductor devices and systems.

## COURSE OUTLINE

**14** Modules to be completed (2 Compulsory Lab Modules, 6 Core Technical Electives, 4 Specialization Technical Electives, 2 Non-Technical Electives)

**45** Contact hours for most of the Core and Specialization Elective Modules

**2** Compulsory Laboratory Modules to be completed by every student

### JOINT DEGREE
Conferred by Technical University of Munich (Germany) and Nanyang Technological University (Singapore)

### APPLICATION-FOCUSED
Full-time research and application focused programme, inclusive of 3-month internship experience and 6-month Master Thesis writing

### INDUSTRY RELEVANCE
Our professors are actively involved in research and cooperation projects with leading industrial companies, allowing them to base the curriculum around the latest technological trends and knowledge

### GLOBAL OPPORTUNITIES
You are able to complete your Internship and Thesis in Singapore or anywhere in the world with a company, university or research institute and look for job opportunities globally

## Programme Timeline Overview

| July | Year 1 | Year 2 | Graduation |
|---|---|---|---|
| **Arrival in Singapore** | • Laboratory Modules<br>• Core Technical Elective Modules<br>• Specialization Technical Elective Modules<br>• Non-Technical Elective Modules | • Non-Technical Elective Modules<br>• Internship<br>• Master Thesis at a company, university or research institute<br>*(Supervised by a NTU or TUM professor)* | **End of Programme** |

Note: This outline is a general reference to the duration of study. A student's actual duration of study may or may not follow this general reference. This outline is subject to change during the course timetable.

# Module Synopsis

## Compulsory Laboratory Modules

### Laboratory 1: Semiconductor Process and Device Simulation

Process models: diffusion, oxidation, implantation. Process variables/targets: doping profiles, junction depths, oxide thickness. Process simulation: Simulate a given sub-micron CMOS process recipe and study profiles and layer structures. Physical models. Numerical algorithms and solutions. Device performance parameters. Short-channel effects. DC simulations. Device simulation: Simulate the DC characteristics of the "fabricated" device and analyze device operation with respect to potential, field, and carrier distributions as well as terminal I–V characteristics. Wafer-split experiment. Device-target vs. process-variable relations. Transistor performance optimization/trade-offs through process variation. Technology development and optimization. Design of Experiment (DOE): Implement a computer experiment to study the scaling characteristics (varying gate length) of the given sub-micron technology. Study the influence of process variations on device performance parameters.

### Laboratory 2: Design and Modeling of Nanodevices

Quantum blockade, quantum Ohm law, quantum conductance, quantum capacitance, quantum confinement, coherent transport, and transmission. Nanowire, transistors, influence of interface properties, low current to high current regime, scattering to ballistic regimes, noise spectrum. Quantum well. Energy subbands and wave functions. k.p methods. Band structure calculation by using single band and 6-band k.p methods. Density of state, doping concentration, and Fermi energy level calculations by using single band and 6-band k.p methods. Intersubband and (intraband) transition. Squared transition element calculation. Absorption spectrum. Cut-off wavelength of photodetector. Influence of Ge composition and well width on peak wavelength of photodetectors. Transition energy. Emission wavelength. Doping concentration. Fermi level. Organic devices (Organic thin film transistors, OLED, organic solar cells). Molecular diodes and switches. Carbon Nanotubes.

## Core Technical Elective Modules *(Choose minimum 6 out of 7)*

### Microfabrication Technology

Photolithography technology. Photoresist technology. Advanced lithography. Metrology defect inspection and analytical technique. Cleaning technology. Wet etching process and technology. Dry etching process and technology. Chemical mechanical polishing. Epitaxy. Plasma enhanced chemical vapor deposition. Atomic layer deposition. Physical vapor deposition.

### Materials for Electronic Devices

Bonding between atoms. Electronic and atomic structures. Basic crystal structures. Energy band. Semiconductors, insulators and organic materials. Defects and doping. Surface and interface. Functional properties of materials. Compound semiconductors. Nanostructures. Electronic ceramics.

### Bioelectronics

Introduction to bionanotechnology. Materials: electrolytes, organic molecules, lipid bilayers, DNA, proteins. Nanofabrication techniques and self-assembly. Biofunctionalization of solid surfaces. Surface analytics and characterization. Electrical biosensors: solid-liquid interface, surface plasmon resonance, quartz microbalance, electrochemical impedance, nanopores, nanowires. Charge transfer in biomolecules: fundamentals and applications.

### Nanotechnology for Energy Systems

Approaches to nanotechnology: bottom-up vs. top-down. Characterization and fabrication issues in the nanoscale. Applications of nanotechnology in electronics, optoelectronics, telecommunications, medicine, biology, mechanics and robotics. Overview of nanotechnology programs in USA, Japan and Europe. Nanomaterials and nanosystems for energy applications. Examples of nanotechnology energy production, energy storage, energy harvesting, and high voltage technologies. A look into the future: electro and photocatalysis, hydrogen production and storage. Economical implications of nanotechnology in the energy field.

### Optomechatronic Measurement Systems

Fundamentals of optomechatronic measurement systems. Light sources and detectors. Refraction, interference and diffraction. Electronic speckle pattern interferometry. Thin film reflectometry as an in-situ deposition sensing technique. Ellipsometry for thin layer analysis. Optical waveguide sensors and their application in renewable energy devices such as wind turbines. Fourier transform infrared spectroscopy for detection of greenhouse gases. Applications of optomechatronic measurement technology in Green Electronics industry, including fundamental understanding of: Patent protection and patent strategy for optomechatronic measurement devices.

### Microstructured Devices and Systems for Green Electronics

Basic physical effects in solid-state microstructured electronic and micromechatronical devices and their application fields (microelectronics, microsensors, microactuators, and microsystems). Characteristic material properties of semiconductors: Intrinsic and extrinsic electrical conductivity, mobility, charge carrier transport by drift and diffusion, carrier generation-recombination, thermal conductivity, energy domain coupling effects (thermoelectricity, piezoresistance, piezoelectricity, thermoelasticity, galvanomagnetism etc.). Basic operational principles of microdevices: pn junction, MOS field effect, unipolar and bipolar electronic devices, power devices, various transducer effects. Phenomenological transport theory: Onsager´s transport model, continuous field models of energy-coupled multi-domain systems, physics-based macro-modeling of microsystems. Selected sensor and actuator application examples.

### Introduction to Power Systems

Structure of the power system: generation, transportation and distribution and electricity consumption. Introduction to typical power plant types including new renewable technologies. Description of the transport, distribution and control philosophy. Introduction to the electricity demand, especially due to new electronic services. Fundamental terms of energy economy and electricity markets. Introduction into smart grids.

## Specialization Technical Elective Modules*

*(Choose minimum 3 out of 7)*

### Lower Power Displays and Solid-State Lighting

Low power flexible displays. OLED displays on flexible substrates. Printing processes for information displays. Evolution of Visible-Spectrum light emitting diodes. LED design principles. Visible-Spectrum LED. White LED. Current topics in solid state lighting.

### Nanophotovoltaics

Third generation photovoltaics. Quantum dot tandem cells. Hot carrier cells. Multiple electron hole pair generation. Impurity and intermediate band devices.

### Green Nanotechnology

Energy flow in environment. Optical properties of nanomaterials. Spectral selective windows. Solar thermal collectors. Solar cells. Cooling and energy harvesting. Electrochemical energy storage.

### Polymer Electronics

An overview of Polymer Electronics. Electronic structure and band theory. Beyond polyacetylene. Optoelectronic properties. Charge transport. Synthesis and macromolecular design. The physics of polymers. Surfaces and interfaces. Polymer transistors. Optoelectronic devices. Photovoltaic devices (organic and dye sensitized solar cells). Polymeric memories.

### Semiconductor Power Devices

Fundamentals of semiconductor device physics: electronic band structure, intrinsic and extrinsic conductivity, mobility, carrier transport by drift and diffusion, carrier generation and recombination, impact ionization, pn-junction, MOS field effect. Power device structures: PIN diode, Schottky diode, bipolar junction transistor, thyristor, power MOSFET, insulated gate bipolar transistor (IGBT). Robustness and destruction mechanisms of power devices: thermal breakdown, electrical breakdown, dynamic avalanche, latch-up in IGBTs, cosmic ray induced failure.

### Advanced MOSFET & Novel Devices

Historical development of mainstream MOSFETs until today: economical, technological, and physical fundamentals. Properties of long channel and short channel MOSFETs, high-field effects, scaling rules. Basics of charge carrier transport, drift-diffusion, Boltzmann-Bloch equation, hydrodynamic transport, ballistics and consequences for IV-characteristics. Advanced MOSFETs, mobility-enhancement, metal-gate, FinFETS, MuGFETS. Hot-electron and ballistic transitors, Impack-MOSFETs, Spintronic devices. Tunneling-MOSFETs, single-electron transistors.

### Modern Semiconductor Devices

Bipolar transistor operation pinciples. Bipolar device modeling. State-of-the-art bipolar structures. CMOS device scaling effects. Semiconductor memories. Future trends and challenges.

## Non-Technical Elective Modules *(Choose minimum 2 out of 7)*

- Business Administration
- Industrial Marketing
- Innovation and Technology Management
- Legal and Safety Aspects in Industry
- International Intellectual Property Law
- Production Planning in Industry
- Modern Developments in Industry

*Disclaimer: Elective modules available for selection are subject to availability. Unforeseen circumstances that affect the availability of the module include an insufficient number of students taking up the module and/or the unavailability of the professor. TUM Asia reserves the right to cancel or postpone the module under such circumstances.

# Admissions Information

## ADMISSION CRITERIA*

- You may apply to our programme if you have completed your Bachelor Degree Programme, or if you are in your final year of Bachelor Degree studies
- Hold or currently enrolled in a Bachelor Degree (completed in at least three years, depending on factors such as the rest of your education background) in **Electrical or Electronics Engineering** or in a closely related discipline
- Submit one **(1) notarised copy of Bachelor Degree Certificate or Enrolment Letter**** (if you have not completed your Bachelor Degree) and one **(1) notarised copy of Academic Transcripts or Mark Sheets****
- Submit **two (2) Recommendation Letters** from two (2) different Professors or Employers
- Submit **one (1) Statement of Purpose** that indicates the reason(s) you are interested in the programme you applied for
- Submit **one (1) Curriculum Vitae / Resume**
- Submit TOEFL / IELTS test score taken no more than two years ago from date of submission of online application
- Submit Akademische Prüfstelle (APS) certificate (Required for applicants who hold a degree from China, Vietnam, or Mongolia)

TOEFL test score requirements: At least 100 for the Internet-Based Test (TOEFL code: 7368)
IELTS test score requirements: Overall IELTS results of at least 6.5

* The full application process is available on www.tum-asia.edu.sg/application-process.

** Documents which are not in English must be translated by a certified translator. All applicants are also required to submit an additional of three (3) notarised copies of Official or Provisional Bachelor Degree Certificate, two (2) notarised copies of full, Official Academic Transcript, and three (3) passport-sized photographs when you have accepted the offer of admissions and are being matriculated into our programme.

## TO APPLY

Applications open 15 October every year. Apply online at www.tum-asia.edu.sg

## FEES

| APPLICATION FEE | TUITION FEE |
| --- | --- |
| SGD 79 is payable for each application per programme | **A total of SGD 34,240+**<br>• The tuition fee will be divided into 3 installments for payment and may be further divided into SGD and EUR amounts.<br>• The tuition fee includes teaching fees, laboratory expenses and cost of mandatory events.<br>• The tuition fee does not include airfare, accommodation, living expenses, and NTU miscellaneous fees (inclusive of registration, IT facilities, matriculation, examination, amenities, copy right, sports, insurance and medical). These fees will be separately paid by the student. |

+ The tuition fee stated is accurate as of 1 August 2018. All fees are subject to revision due to currency fluctuations, at the discretion of TUM Asia. All fees quoted are inclusive of 7% Singapore's Government Goods & Services Tax. Please refer to our website for fee updates.


Campus of Nanyang Technological University (NTU)


# Studying With Us

“Talents Are Our Assets, Reputation Is Our Return”

## Entrepreneurial Thinking and Engagement

Globalization is now an inevitable force that is here to stay. At TUM Asia, our classroom reflects this diversity with an enrolment of over 28 nationalities. This means that we foster a vibrant learning environment where the student learns not only from the textbook but also through the lives of their counterparts. Classroom ideas are synthesized across the diverse economic realities and students learn to see from multiple vantage points, creating a capacity to solve problems in creative ways. The unique joint degree programme not only equips the student with technical and scientific knowledge, but with an enriched curriculum consisting of business and cultural modules.

## TUMCREATE

TUM is known for its research capabilities and strength in innovation. As such, TUM Asia spearheaded the set up of TUMCREATE as a base of research in Singapore. TUMCREATE is a joint programme between Technical University of Munich (TUM) and Nanyang Technological University (NTU). The electromobility institute brings together the expertise and innovation of Germany and Singapore, to drive innovation to shape the future of sustainable mobility by tackling issues ranging from the molecues to the megacity. **Graduates from the TUM Asia Master programmes have the opportunity to apply for positions at TUMCreate, especially if your interest lies in the area of transportation and mobility research.**

## Highest International Standards

You will be studying with the world’s best professors from TUM and NTU, as well as experts from the industry. Not only will the student benefit from professors who are actively involved in research, one will also receive a holistic learning experience with the engagement of local lecturers from academia and industry. Our TUM modules are covered by professors who fly in from Germany on an exclusive teaching basis, to ensure that students get the undivided attention of their lecturers.

> **“With the increase in our population and the growth of our economy, we must be more careful about how our industrial activities and resource consumption impact the environment. Electronics is one of our most developed and pervasive technologies. In this perspective, green electronics show new ways to make electronic devices that are more attentive to the consequences of the environment.**

Prof. Dr. Alessio Gagliardi
Professor, Technical University of Munich
Simulation of Nanosystems for Energy Conversion

# DID YOU KNOW THAT A PART OF YOUR GADGET - COMPUTER, MOBILE PHONE, TABLET OR VIDEO CONSOLE - WAS DESIGNED OR MANUFACTURED IN SINGAPORE?

## Clean Technology: Singapore's Environmental Commitment

Singapore is the leading clean energy hub in the region and the prime location for major cleantech companies. Singapore's strengths in manufacturing sectors such as electronics, precision engineering and chemicals, connectivity with regional markets, access to skilled international talent, and extensive supplier base are beneficial to cleantech companies. Singapore aims to further develop its cleantech industry, particularly its solar energy capabilities due to rising energy demands, climate change concerns and rapid technological advances. Other important growth areas are smart grids, green buildings, and energy efficiency.

## The Semiconductor / Photovoltaics Industry in Singapore

In Singapore, electronics contributes 5.2% to the country's gross domestic product (GDP). With the economic center gradually shifting to Asia, Singapore's geographic location, open culture and strong fundamentals in the electronics industry makes her a choice location. The semiconductor industry in Singapore has the highest growth potential and is currently the fastest growing industry sector. The Photovoltaics industry in Singapore aims to offer a comprehensive array of renewable energy and eco-friendly technologies by developing improved clean electricity capabilities through solar technology.

## Graduates Employability

- Graduates in Green Electronics can seek employment in research institutes, companies related to green electronics all over the world, or go for higher studies.
- Graduates can play professional roles in process development, process integration, as well as characterization, and device modelling in the Semiconductor industry.
- Graduates in Green Electronics have extended career opportunities, not only in the electronics manufacturing industry, but also in the photovoltaic, low power display, nano- and bio-material, sensor & communication industry.

**1** CleanTech Park is Singapore's 1st eco-business park. It was developed for forward looking corporations that have embraced environmental sustainability.

**3** Three of the world's top six outsourced semiconductor assembly and test companies are located in Singapore.

**20** Singapore is home to approximately 20 semiconductor assembly and test operations.

**24** In 2014, 14 silicon IC wafer fabs, 4 compound semiconductor wafer fabs, 3 Micro-Electro-Mechanical Systems (MEMS) wafer fabs and the top 3 suppliers of hard disks are located in Singapore.

**25** Electronics is the major industry underpinning Singapore's economic growth, it contributes 25% of the total manufacturing value-add.

**30** The solar sector in Asia is expected to contribute to about 30% of the global solar market by 2015, compared to just over 10% in 2010.

**50** Singapore is well positioned within the sunbelt, receiving about 50% more radiation than temperate regions such as Japan or Germany, both major hubs for solar technology today.

**"The Green Electronics Master programme provides students a unique opportunity to acquire high-level training in advanced electronics, as well as to study the interaction of electronics with the environment. The distinctive combination of these capabilities will equip the students to make key contributions in the sustainable development of all kinds of electronic devices."**

Professor Dr.-Ing. Dr. h.c. Alexander W. Koch
Chair of Measurement Systems and Sensor Technology, MST
Technical University of Munich (TUM)

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German Institute of Science & Technology - TUM Asia Pte Ltd
CPE Registration No.: 200105229R
CPE Registered Period: 13/06/2017 to 12/06/2023

All information is accurate at the time of printing and is subject to change without prior notice.
Published in August 2018.

+ As rated by Academic Ranking of World Universities (Shanghai Ranking) 2011-2013, 2016 and 2015-2018 QS World University Ranking
++ As rated by Academic Ranking of World Universities (Shanghai Ranking) 2016
* As rated by the Times Higher Education University Ranking 2016
^ As ranked by the Global University Employability Ranking 2017
# As ranked by Academic Ranking of World Universities (Shanghai Ranking) 2017/2018 and 2013/2014 QS World University Ranking