



OLED

Materials & Technology
for Display and Lighting



Novaled – a leading OLED player

Jae-Hong Choi, CFO

Gerd Günther, CEO

Novaled offers core materials and technologies for superior OLEDs in display and lighting as well as for further high-performance organic electronics (OE).

Novaled's expertise is unique in the OE field for the way it combines physics, chemistry and engineering support.

With more than 500 patents granted or pending, we maintain a strong IP position in OLED technology.

With its proprietary OLED materials and knowledge, Novaled is a pioneering company in the Dresden region – home to Europe's largest cluster of organic semiconductor industry.



Youngkwon Kim, CTO



Dresden/ Germany



Three skills uniquely combined
for customer success





Engineering

highly experienced in processing of materials and device testing



Device Physics

expert in developing OLED technologies and devices

Organic Chemistry

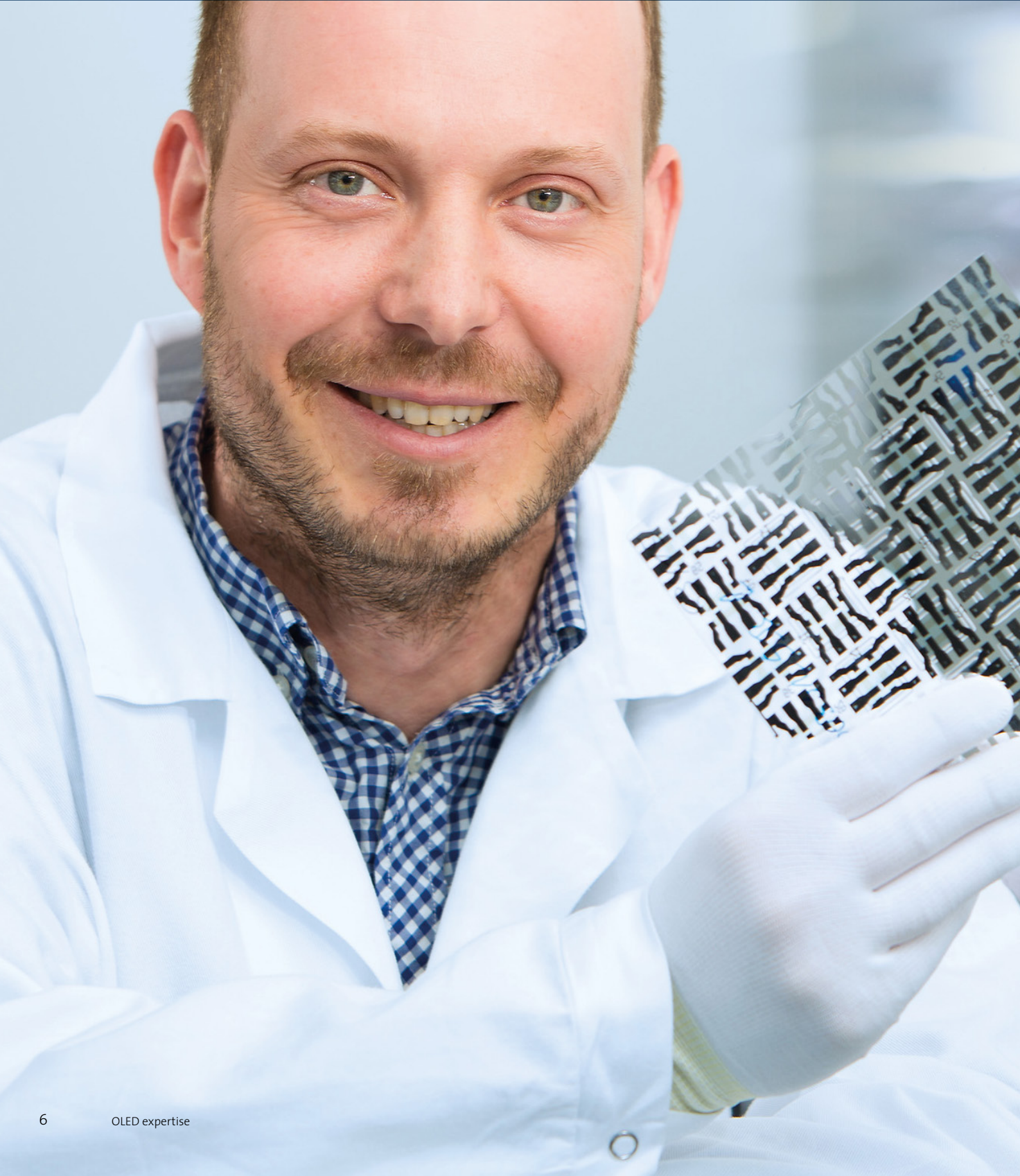
expert in synthetic and analytical chemistry for superior organic electronic materials

In contrast to other suppliers, Novald starts from the device side. As an expert in device physics, we are translating performance requirements into the right organic chemistry for customer's applications.

Based on this, we create and supply best-fitting materials for improved device performance easy to handle in mass production.

Novald's unique combination of these three skills – device physics, synthetic chemistry and processing – ensures a deep understanding of all aspects of optical properties, stack architecture, degradation mechanisms (chemical and physical) and device processing, as well as doping, transport and other material qualities. This enables us to deliver best-in-class service and products to our clients.

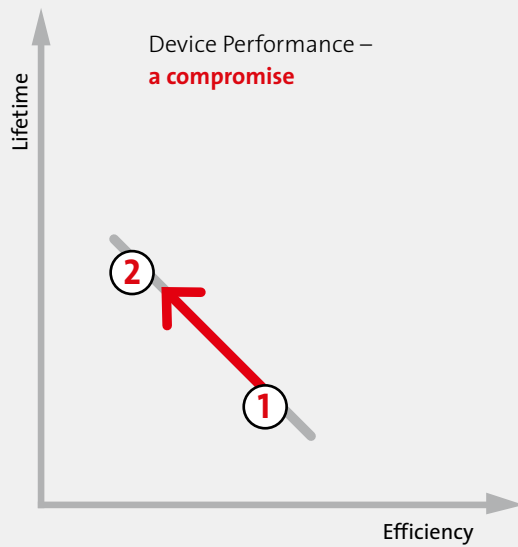
OLED expertise for outstanding device performance



Novaled's unique expertise ensures both excellent OLED efficiency (light output) and operational stability (lifetime) for the customer.

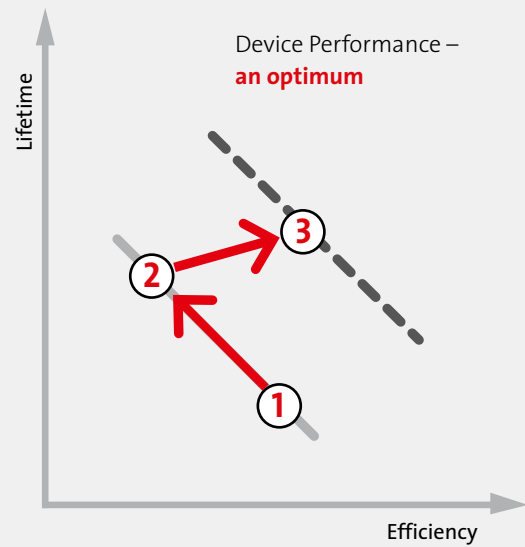
Our clients benefit from our advanced services by enhancing product performance and fine-tuning their manufacturing on a mass production scale.

Novaled solving customer's dilemma



Standard approach:

a trade off:
high efficiency (1) **or** long lifetime (2)



Novaled approach:

break out of trade-off regime:
long lifetime **and** high efficiency (3)

- ▶ improve selected parameters based on device physics expertise
- ▶ improve parameters based on material set plus process and device optimization



novalled inside

Organic doping for performance gains

Novaled Doping – Significant performance gains

Novaled PIN OLED technology focuses on charge transport layers in organic devices. By doping these layers and applying Novaled's technology as well as transport and doping materials, devices achieve highest performance values.

Novaled's OLED doping results in a unique combination of high power efficiency and long lifetime.

Result of Novaled doping:

- ▶ Considerably enhanced hole and electron-transport as well as charge carrier injection

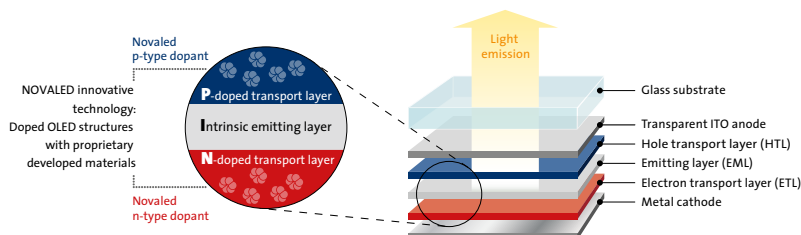
Advantages for our OLED customers:

- ▶ Extremely low operating voltage
- ▶ High efficiency and lifetime in RGB and white
- ▶ Transparent, alkali metal free OLEDs
- ▶ Easy integration on all substrates
- ▶ Ability to reduce process steps (such as plasma substrate treatment)



Architecture of a bottom-emitting OLED based on Novaled PIN OLED technology

Emission layer incorporated between doped transport layers



Working principle of Novaled doping:

- Hole injection from the anode
- Holes are transported by p-doped, highly conductive hole transport layer (p-HTL) to the emitting layer (EML)
- Electron injection from the cathode
- Electrons are transported by the n-doped, highly conductive electron transport layer (n-ETL)
- Recombination of electrons and holes in the EML; light is emitted



Taylor-made materials for mass-produced OLED devices

Added value for customers

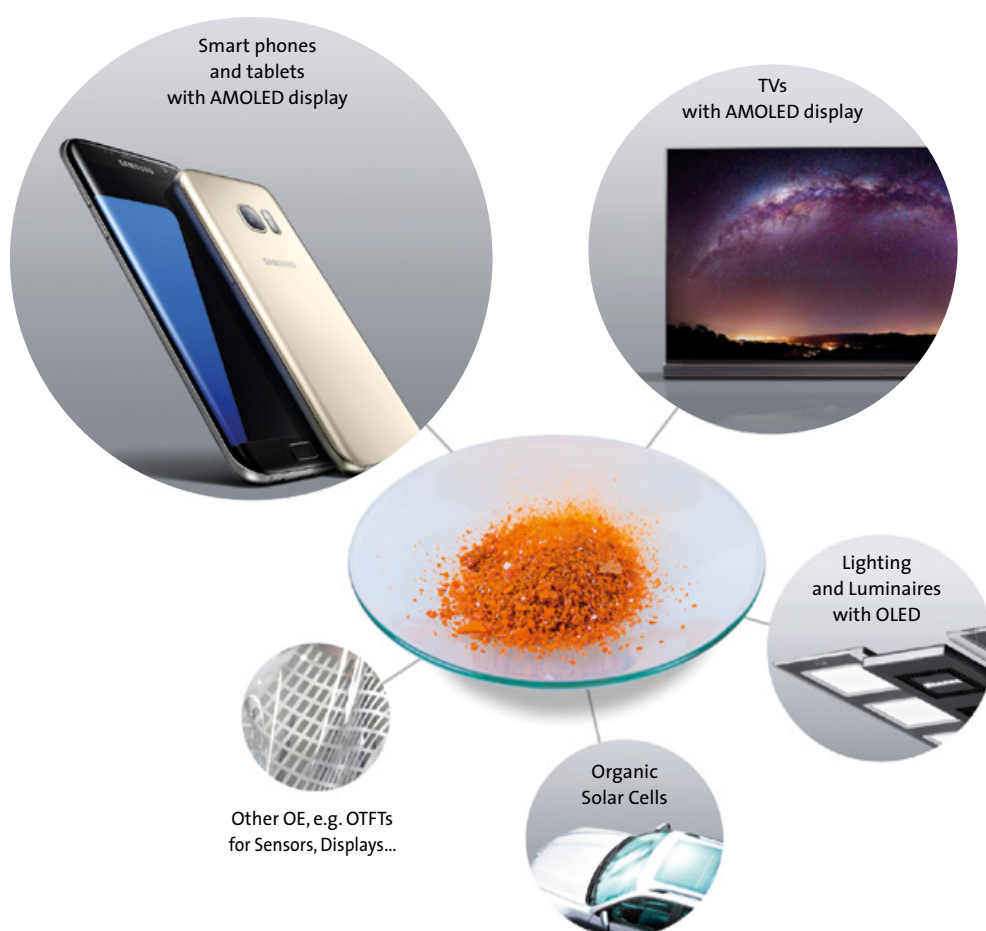
Novald offers high-performance materials for organic electronic devices such as OLEDs. Novald materials lead to significantly increased efficiency and lifetime of organic electronic devices.

The p and n dopants exhibit some of the strongest oxidation and reduction potentials available in molecular structures. Additional dedicated materials further increase OLED device performance characteristics, including improved angular light emissions.

Thermal stability, enhanced processability and ease of handling are key features of Novald materials. Reducing costs is another factor to which Novald materials can contribute.

Novald materials for different applications

Our materials are designed to deliver customer benefits to mass-produced devices.



Novald transport and doping materials are well established in the OLED display and OLED lighting markets.

Our materials are also known for improving the functionality of OPV devices and are valued for further applications.



Improved OLED functionality

Novaled materials enable OLED manufacturers to harvest benefits such as better product performance, simpler stack design and easier manufacturing of their products.

Novaled materials

Customers can select from a wide range of single as well as composite dopant, transport and interlayer materials to best serve individual structures.

We ensure high-quality and on-demand availability of mass production volumes.

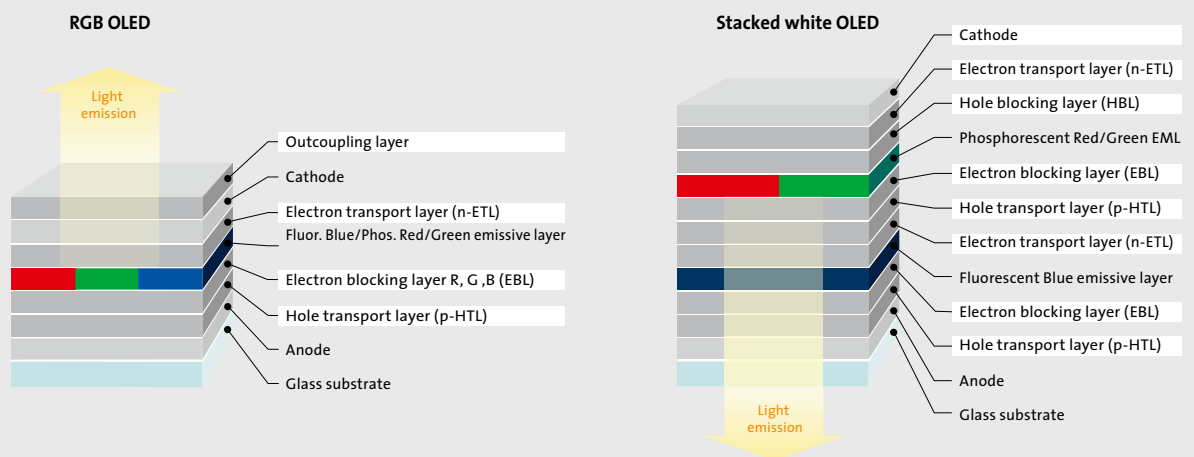


	Hole Side (p-HTL)	Electron Side (n-ETL)
Transport & Blocking Materials	NHT	NET
Dopant Materials	NDP	NDN
p-n-junction Materials	NET, NHT, NDP, NDN	

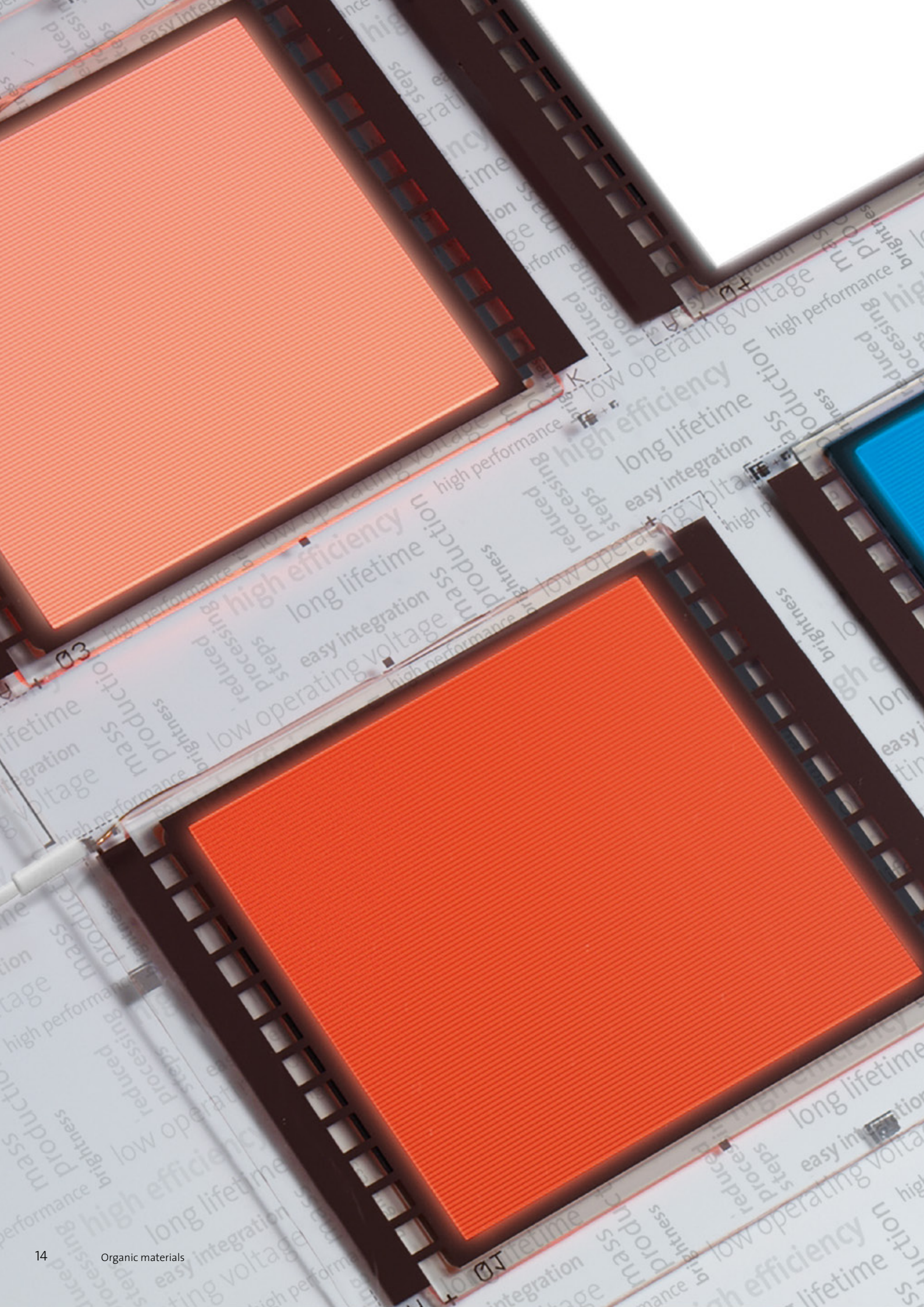
Novaled materials adapt to a wide variety of emitter material solutions.

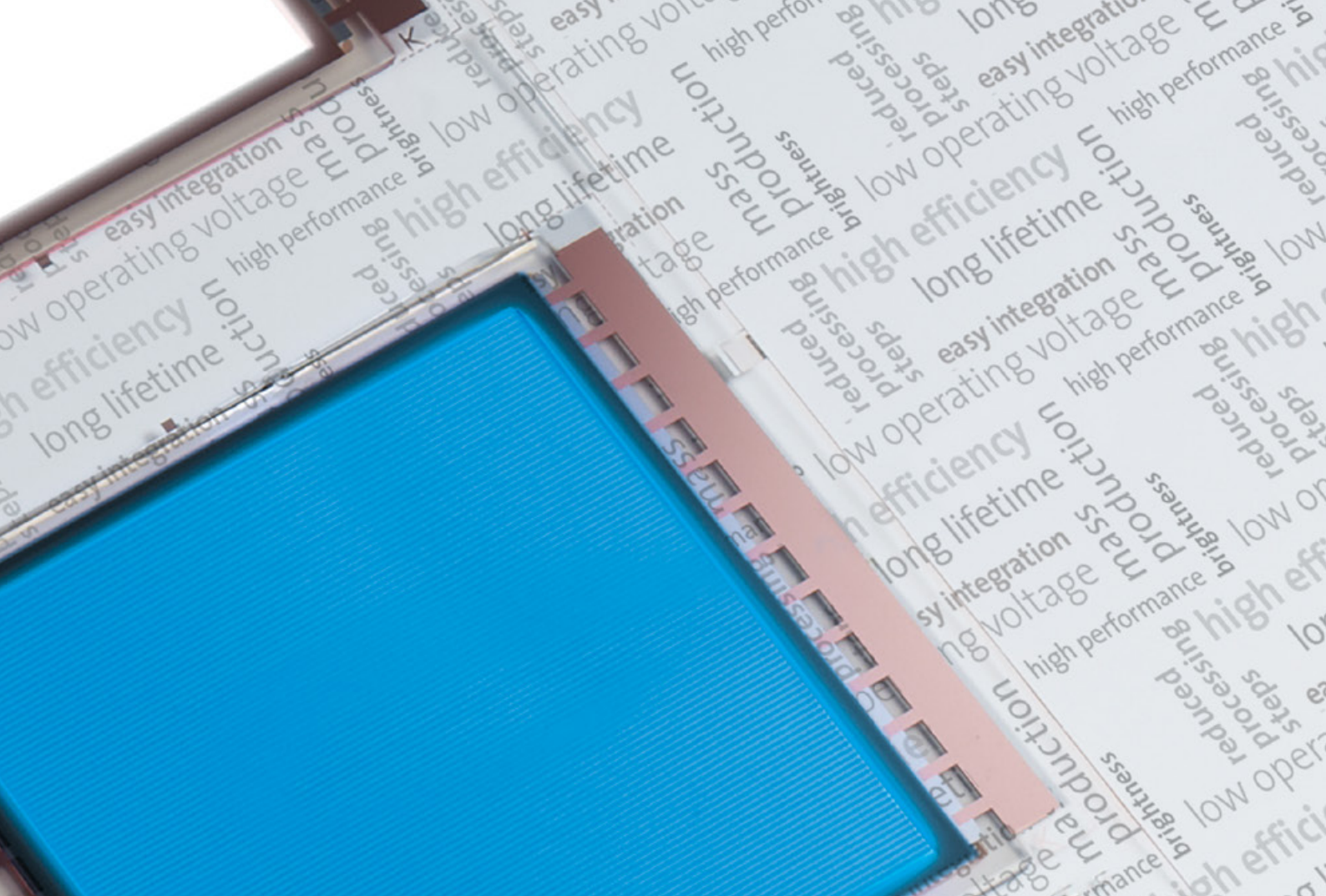


Novald covers the entire OLED stack with advanced organic materials
 except the emission layer



OLED stacks can be very different with regard to composition and number of layers





Benefits to the customer

Doping and transport materials

- ▶ enable very low operating voltages and sustain or improve the efficiency and lifetime of OLED devices
- ▶ provide a unique combination of OLED performance and process compatibility
 - reasonable evaporation temperature range for simple process control
 - high device stability in the absence of matrix layer dopant diffusion even at high temperatures
 - low vapor pressure, no cross-contamination
- ▶ can be adapted to solution processes (high throughput coating and printing techniques)
- ▶ Solution-processed Novaled p-HTL materials improve yield

p-n-junction materials for stacking OLEDs

- ▶ enable very low operating voltages
- ▶ drastically improve operational stability
- ▶ reduce absorption losses

Materials from LAB to FAB



Customers benefit from our highly skilled engineering

We make sure that high-performance Novaled materials are easy to handle in a mass-production environment. State-of-the-art equipment and top-edge tests guarantee smooth processing on customer's tools.



A unique service for material characterization

Novaled provides in-depth screenings of processing properties of our organic materials under mass-production conditions, e.g.:

- ▶ simulating process environment of mass-production evaporation source approach
- ▶ precise T_s (onset temperature) measurement (± 2 Kelvin in high vacuum)
- ▶ reliable long-term stability data of materials

This ensures a reproducible material characterization for a straightforward transfer to production of customers.

Ready for new applications and processes

For new and future applications, our customers can rely on our in-depth knowledge of processing materials in flexible devices and on adjusting ink systems (X-HTL) on customer process equipment.

World class materials in shortest lead times

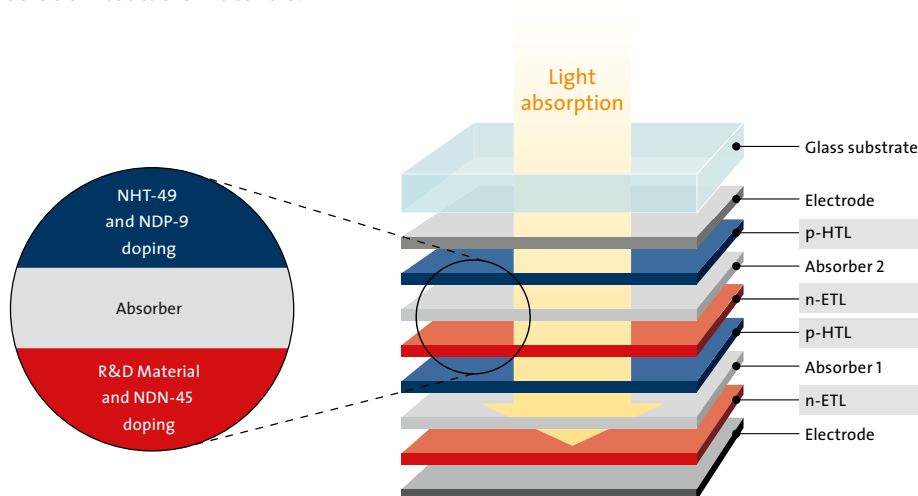
Novaled's manufacturing of proprietary materials is based on a comprehensive network of Custom Manufacturer Organisations (CMOs) for synthesis and sublimation. By this Novaled ensures

- ▶ a broad variety of chemical production skills
- ▶ superior material performance and quality

Close collaborations issued at R&D stage enable shortest lead times of Novaled materials in required quantities and support customers with world-class products along their lab-to-fab process.



Novaled doping technology and materials are used beyond OLED applications to enhance the performance of other organic electronics (OE). To maintain compatibility with the variety of processes used in such applications, Novaled offers vacuum and solution-coatable materials.



Organic Solar Cell with Novaled technology and materials

Novaled materials facilitate organic photovoltaic devices (OPV) with:

- ▶ aligned energy level for high open-circuit voltage
- ▶ optimized charge transport for high fill factor
- ▶ optimized thickness and tandem structure for harvesting the entire solar spectrum
- ▶ high stability and simplified manufacturing
- ▶ for example: 12% efficiency OPV with Novaled PIN concept and materials demonstrated by Heliatek (2013)

This ensures a reproducible material characterization for a straightforward transfer to production of customers.

Materials for advanced organic electronics applications



Novald – New Headquarters



Facts

- ▶ Total area: 10.600 qm
- ▶ Construction: 2 years
- ▶ Move in: March 2019

New R&D Center

- ▶ Clean Rooms class ISO5 and ISO7
- ▶ Chemistry labs with reactor rooms
- ▶ Sublimation

Listed Monument 'Old Mill'

- ▶ Administrative building
- ▶ Open space offices
- ▶ Cafeteria & Lobby



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Novald provides its customers with proprietary organic materials and complementary innovative technologies for superior OLEDs in display and lighting. Partners benefit from Novald's unique expertise in combining physics, chemistry and engineering support.