

OLED Materials & Technology

for Display and Lighting Applications





Novaled –
a leading OLED player



noval
Headquartered
in Dresden/Germany

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

Noval'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, Noval is a pioneering company in the Dresden region – home to Europe's largest cluster of organic semiconductor industry.



Dresden/Germany

Three skills uniquely combined for customer success





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.

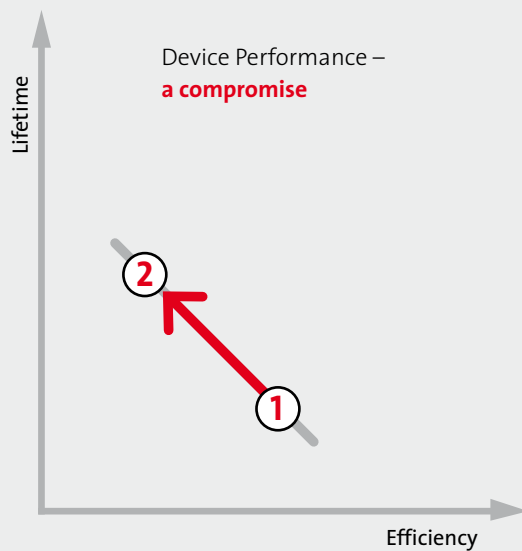


1 OLED expertise for outstanding device performance

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

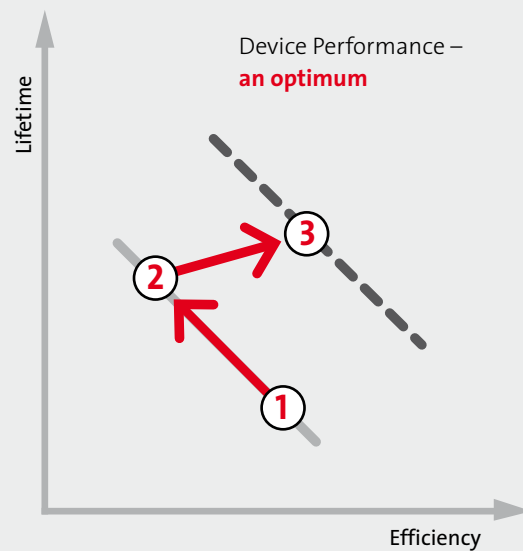
Our clients benefit from our advanced services by enhancing product performance and fine-tuning their manufacturing on a mass production scale.

Novald solving customer's dilemma



Standard approach:

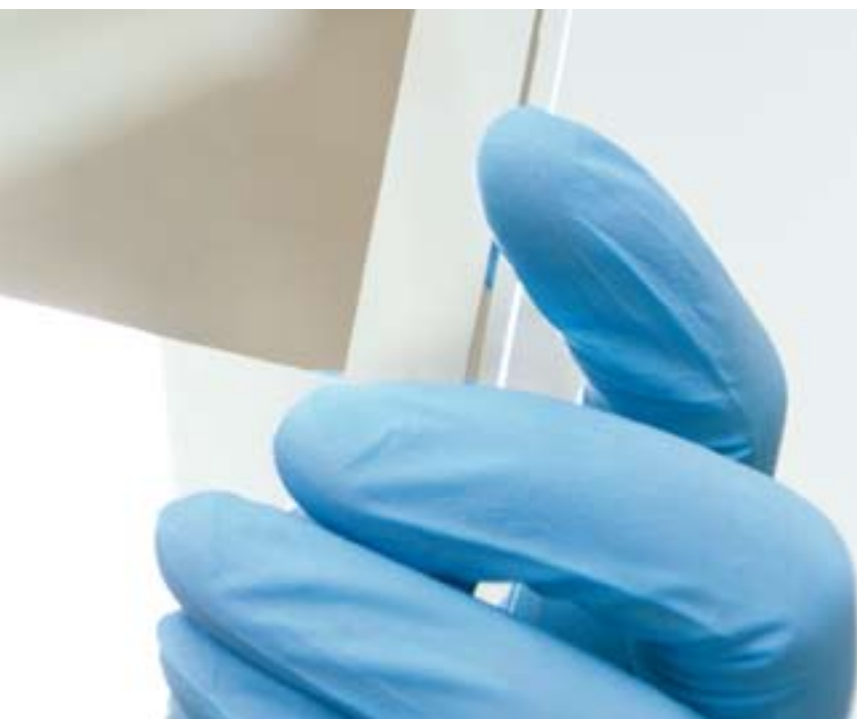
a trade off:
high efficiency (1) **or** long lifetime (2)



Novald 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





1 Organic doping for performance gains

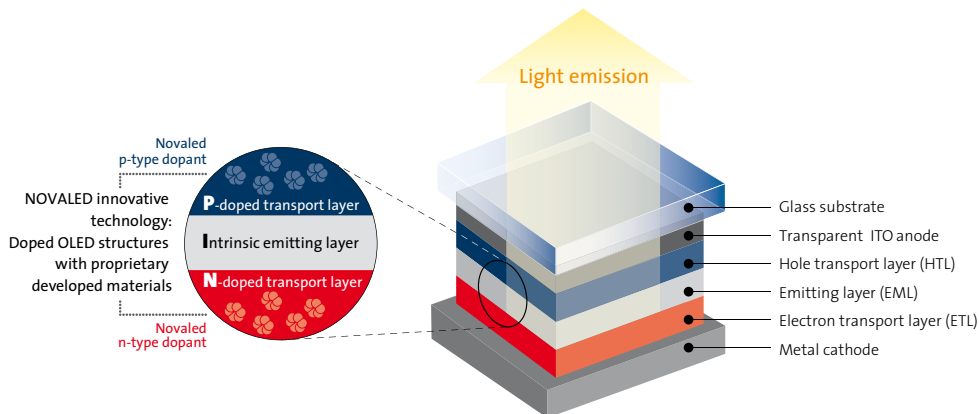
Novaled Doping – Significant performance gains

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.

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

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)



2 Taylor-made materials for mass-produced OLED devices

Added value for customers

As an expert in synthetic and analytical chemistry, 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 tailor-made 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 such as organic TFTs (OTFT).

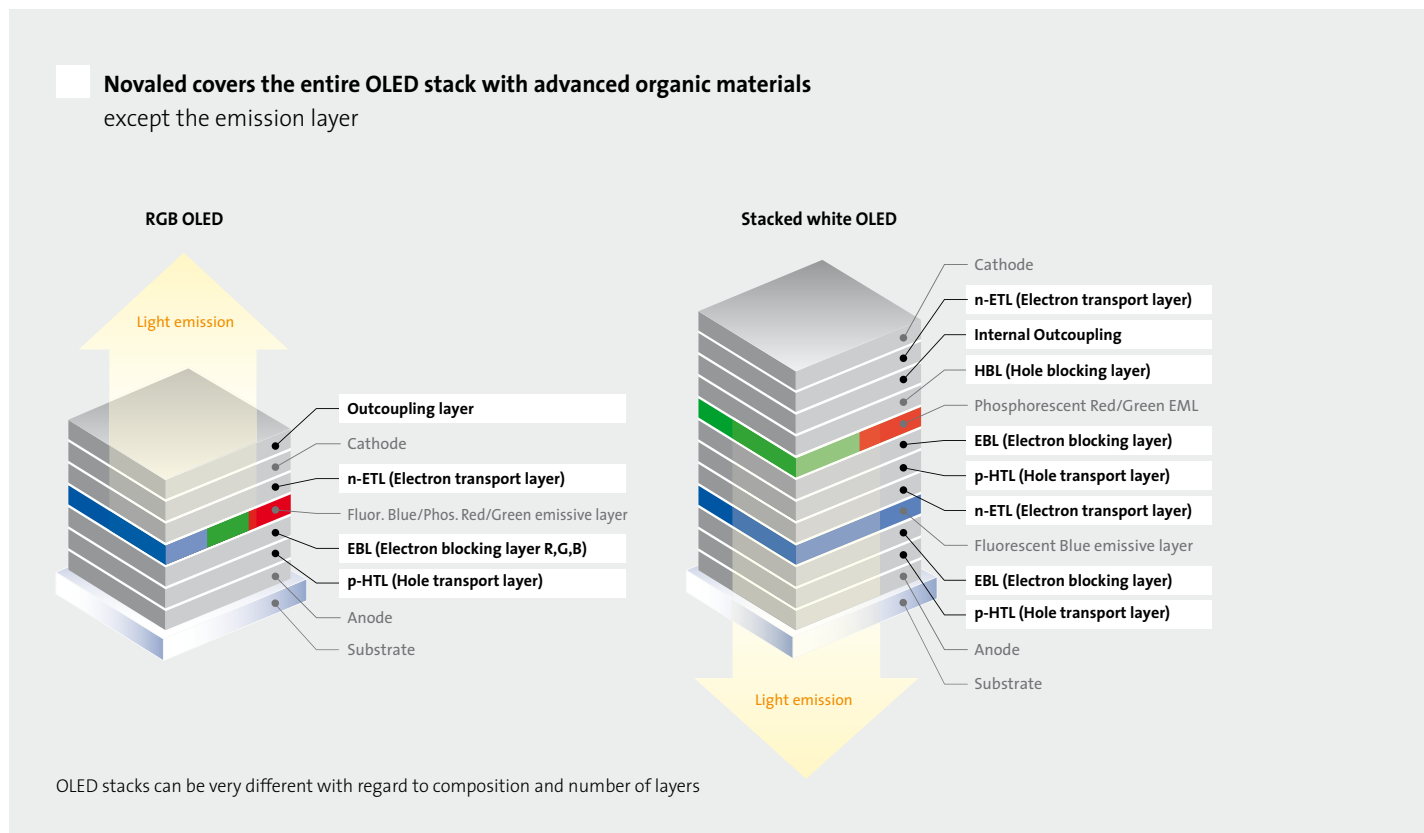




Improved OLED functionality

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

Novaled is developing molecular p and n dopants, hole and electron transport materials, interlayer materials and outcoupling materials for light extraction to adapt to a wide variety of emitter material solutions.



Customers can select from a wide range of single as well as composite dopant, transport, interlayer and outcoupling materials to best serve individual structures. We ensure high-quality and on-demand availability of mass production volumes.



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
- ▶ allow metal-free stacked structures

Optical outcoupling materials

- ▶ improve OLED device light extraction and thereby significantly increase efficiency levels
- ▶ enable white top-emitting OLEDs without microcavity effects
- ▶ inhibit viewing angle-dependent color shift

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



3 Materials from LAB to FAB

Customers benefit from our highly skilled engineering

As an expert in synthetic and analytical chemistry, 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

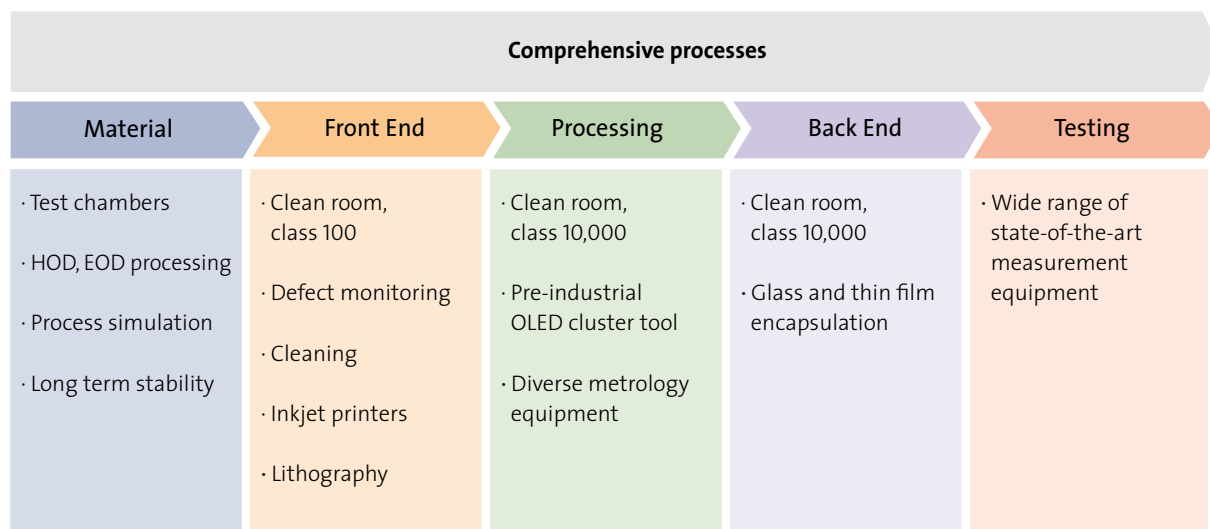
Novaled provides in-depth screenings of processing properties of our organic materials under mass-production conditions:

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

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

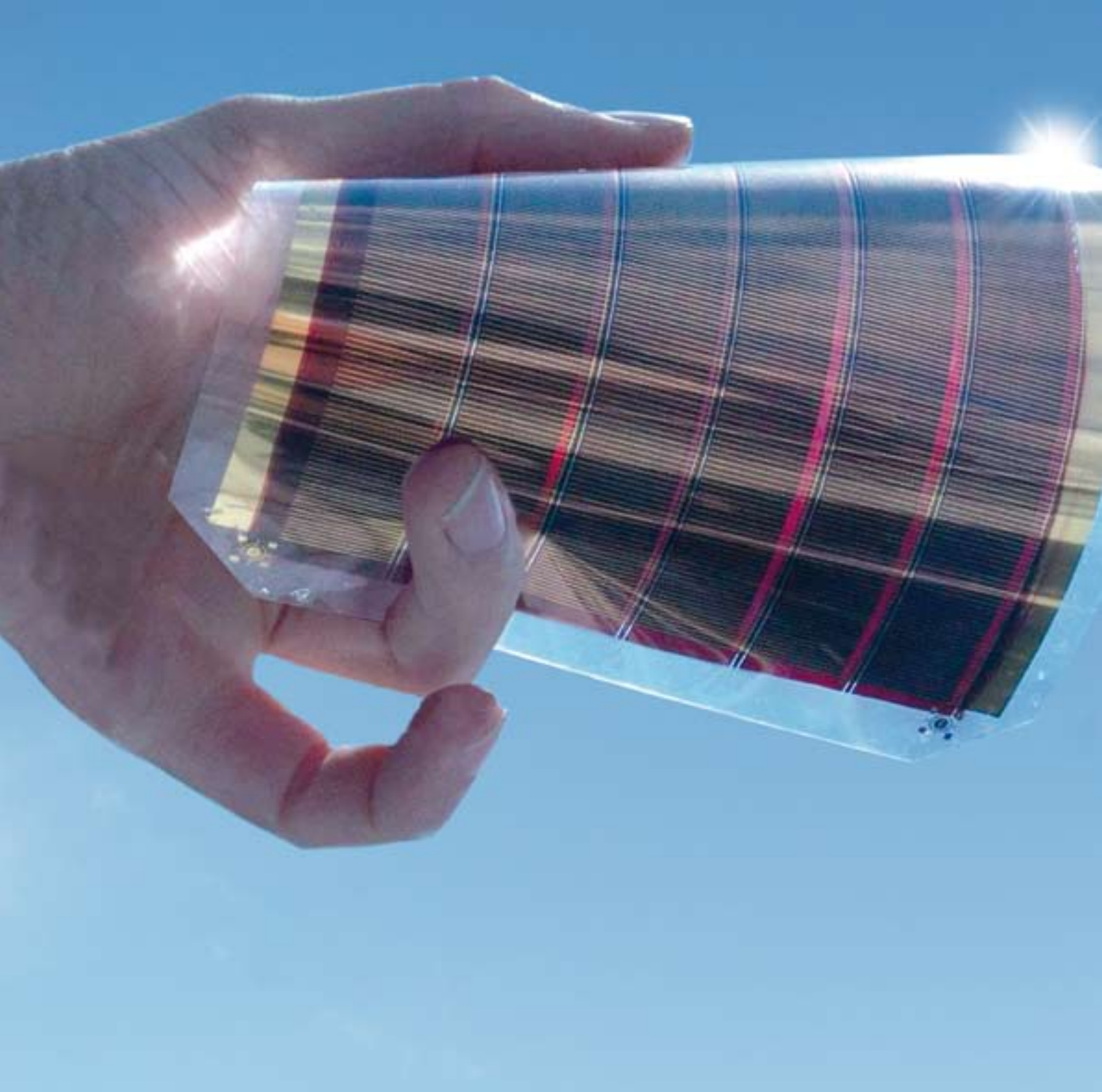
Ready for new applications and processes

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.



Novaled – highly skilled in all processes relevant to OLED manufacturing with state of the art tools and processes





Materials for advanced organic electronics applications

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.

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)

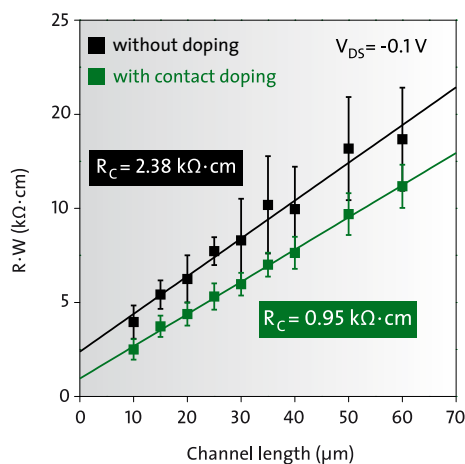
This ensures a reproducible material characterization for a straightforward transfer to production of customers.

Injection materials for OTFT applications

The success of classical silicon CMOS technology is linked to the ability to make p-type and n-type transistors. With Novaled p- and n-type dopants such p- and n-type organic transistors (OTFTs) can be realized too.

Controlled p- and n-doping by using Novaled PIN OLED® technology allows for:

- ▶ reduced contact resistance at source/drain
- ▶ use of less expensive contact material (replace Gold)
- ▶ definition of conduction type for a wide range of materials
- ▶ increased mobility
- ▶ control of threshold voltage
- ▶ high response frequency



Width-normalized resistance as a function of the channel length for pentacene OTFTs with and without area-selective NDP-9 contact doping. By linear extrapolation the contact resistance (at $L=0\ \mu\text{m}$) is extracted. Transistors without doping exhibit a contact resistance of $2.38\ \text{k}\Omega\cdot\text{cm}$, whereas NDP-9 contact doping reduces this value to $0.95\ \text{k}\Omega\cdot\text{cm}$.

Source: Hagen Klauk, Max Planck Institute for Solid State Research





Novald GmbH is a leader in the research, development and commercialization of technologies and materials that enhance the performance of OLEDs (organic light-emitting diodes) and other organic electronics.

Novald offers OLED product manufacturers a unique combination of proprietary technology, materials and expertise, and is currently the only company licensing and selling organic conductivity doping technology and materials for use in the commercial mass production of display products in the OLED industry.

The company was founded in 2001 and is headquartered in Dresden with sales offices in Asia.



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