

LIQUID-CRYSTAL- WINDOW TECHNOLOGY

LICRIVISION™ – CRYSTAL CLEAR VISIONS
FOR ARCHITECTURE



 licrivision™

EMD Performance Materials
is a business of Merck KGaA,
Darmstadt, Germany.



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BLENDING CREATIVITY WITH EFFICIENCY,
LICRIVISION™ TURNS WINDOWS INTO
ELEGANT, INTELLIGENT AND ENERGY-
RETAINING DESIGN COMPONENTS

LICRIVISION™

FOR SOPHISTICATED ARCHITECTURE

Modern architecture is all about transparency and light. Pairing the aesthetic qualities of glass with functional shading and energy efficiency, however, is a challenge. Now, EMD has revolutionized the way windows are seen and used. With its new licrivision™, controlling the amount of natural daylight penetration is just a flip of a switch away. Eliminating of the visual clutter of mechanical blinds, unwanted glare or obstructed views, Liquid Crystal Windows (LCW) with licrivision™ enable fast, sleek, easy-to-use shading solutions on demand. LCW is haze-free and therefore retains the view – even in the dark state.

Depending on the amount of visibility and outlook desired, licrivision™ allows for optimal protection of privacy: With its privacy-mode, the glass can be turned opaque or transparent.

licrivision™ provides new ways of designing with glass, aimed for bespoke large-scale glass skins. It strives for a clean visual appearance in line with sophisticated premium design aspirations.

With more than 110 years of experience in the liquid crystals business, Merck KGaA, Darmstadt, Germany, is the world's leading supplier for the display industry. Focused on applications such as flat screen TVs and smart phones, EMD is now expanding its expertise with a new, unique and proprietary technology for intelligent window systems – Liquid Crystal Windows. EMD is the liquid crystal material supplier for this new application and aims to be the driver for this emerging technology.

With EMD providing the materials and its partners producing the

glass, windows and facades, licrivision™ forever changes switchable glass use in architecture. LC windows go beyond the look, feel and functionality of regular shading solutions, smart or not, replacing existing systems. licrivision™ is a dynamic glass using the Liquid Crystal Window technology.



LIGHT AND BRIGHT OR COOL AND DIMMED – LICRIVISION™ PRESENTS UNIVERSAL STYLE AND DESIGN OPPORTUNITIES FOR INDIVIDUAL COMFORT AND FUNCTIONALITY NEEDS

licrivision™ can transform any window into an innovative glass design feature that flexibly adjusts to the functional and atmospheric needs and blends into any environment while saving energy and cost. Switchable Liquid Crystal Windows with licrivision™ change light transmission properties by effectively controlling the amount of light and heat passing through the glass.

With the privacy-mode rendering the glass opaque or transparent, your privacy is always protected.

EMD's exceptional track record in the liquid crystal industry allows licrivision™ to excel in all relevant product areas of a truly intelligent window system:

- Ultimate design freedom with almost no aesthetic limitations in terms of functionality, applicable shapes or styles and a broad spectrum of color options. Current size restrictions will be solved in the near future.
- High-quality look and feel with continuous switching provide unparalleled comfort of use and adjustability, and ensure new levels of invisible integration.
- Unique value proposition through cost, space and material efficiency.
- Optimal protection of privacy or total transparency: the privacy-mode turns the glass opaque or transparent at the flip of a switch.

ONE WINDOW, MANY ADVANTAGES



**ULTIMATE
DESIGN
FREEDOM**

SLEEK DESIGNS WITH NO LIMITATIONS BECOME POSSIBLE WITH LICRIVISION™, OFFERING ULTIMATE INTEGRATION, UNLIMITED USABILITY AND FLEXIBILITY AS WELL AS HIGH STYLE

People move into glass buildings for the light and the views, but they put up blinds mainly because of the sun. A sleek curtain-wall facade, glass roof or floor-to-ceiling window all face the same dilemma: how to create a perfect balance between how much light is needed and how much of it is wanted? And how does light relate to other conditions such as heating, cooling, outside view or privacy?

licrivision™ controls light on demand, instantly creating a comfortable atmosphere at the flip of a switch. It offers exceptional design freedom from interactive facades to glass shapes, sizes, and colors. With extremely fast and continuous switching between bright and dark and seamless system integration, LC windows with licrivision™ provide a striking balance between functional efficiency and aesthetic flexibility. From private homes to high-end public spaces, licrivision™ ensures style and design factors within a

wide range of shading applications through undisturbed simplicity of detailing. Thus, licrivision™ provides crystallizing moments, magnificent vistas and clear perspectives.

EMD Performance Materials is working on a number of pilot projects and exploratory studies implementing licrivision™ design applications. Renowned architecture offices conducted tests and simulations for temporary or mobile buildings for exhibitions and trade shows, glass facades and awnings as well as art installations and sculptural structures to create visions for reprogramming architectural environments. These applications will contribute to the qualities and potential of the new technology to present a customer-tested product in the near future. With holistic and integrated solutions at the center of

licrivision™ abilities, the design and planning processes were analyzed with regard to the results of temperature impacts on room climates. First renderings feature facade design possibilities and dynamic design elements such as segmentation, dynamic color, building integration and display technology, thus providing an impressive outlook on the manifold possibilities of EMD's licrivision™.



SHAPE, SIZE, COLOR OF CHOICE AND PRIVACY

LICRIVISION™ PRESENTS AN UNPARALLELED DESIGN AND SPACE EXPERIENCE IN ANY WAY, ANY SHAPE OR ANY FORM IMAGINABLE, INSIDE AND OUTSIDE

Architecture invariably requires a creative vision, but shaping ideas and giving them style is often limited by purely technical approaches to window shading designs. licrivision™ is not tied to fixed pre-fab concepts. It can be applied to any conventional glass, is adjustable to custom shape, size, color (in development) and build-up to specific requirements and standards. Architects can play with almost infinite creative and technological possibilities.

SHAPE

Shaping ideas: licrivision™ allows for irregular forms without detrimental effects on appearance or performance, which guarantees maximum design freedom beyond standard solutions.

SIZE

Selecting size: licrivision™ can be applied to almost all conceivable sizes. The technology has no intrinsic limitations regarding size. No additional bus bars or other disturbing elements are needed, and switching speed is not impacted by the size.

COLOR

Colorful concepts: licrivision™ provides a color choice that can be tailored to the architect's specifications without performance loss. licrivision™ is currently offered in several colors. With a color rendering index in neutral grays, it offers full freedom of aesthetic expression. licrivision™ can also dynamically substitute shading solutions such as coating or printing solutions for glass ceilings and facades.





PRIVACY

Private stays private: an additional module of the LCW platform gives your private sphere some atmosphere, making conventional glare protection like blinds obsolete. Seeing but not being seen is the principle that makes licrivision™ an ideal visual protection for personal and professional environments: inside or out, whether for a glassed-in conference space of an office or the see-through bathroom at home, licrivision™ combines highest privacy protection with ideal illumination.

ENTERTAINMENT

Visibility versus view: peeking into the kitchen of a restaurant provides trust and is part of the entertainment. licrivision™ offers new aesthetic solutions with the right amount of transparency – because we don't really want to hear or see everything. Thus, licrivision™ allows for sheer endless opportunities to divide spaces with beautiful glass-screens and still allow for panoramic views.

SHOPPING ENVIRONMENTS

Precious protection: exclusive products deserve a first-class presentation, but anything dramatically lit also needs light protection. licrivision™ offers a multitude of applications for store windows and displays, allowing a balance of natural light and artificial lighting with continuous switching. Shopping becomes an experience with licrivision™'s almost endless applications in complex retail environments. Wherever glass is being used, no unsightly blinds are needed.

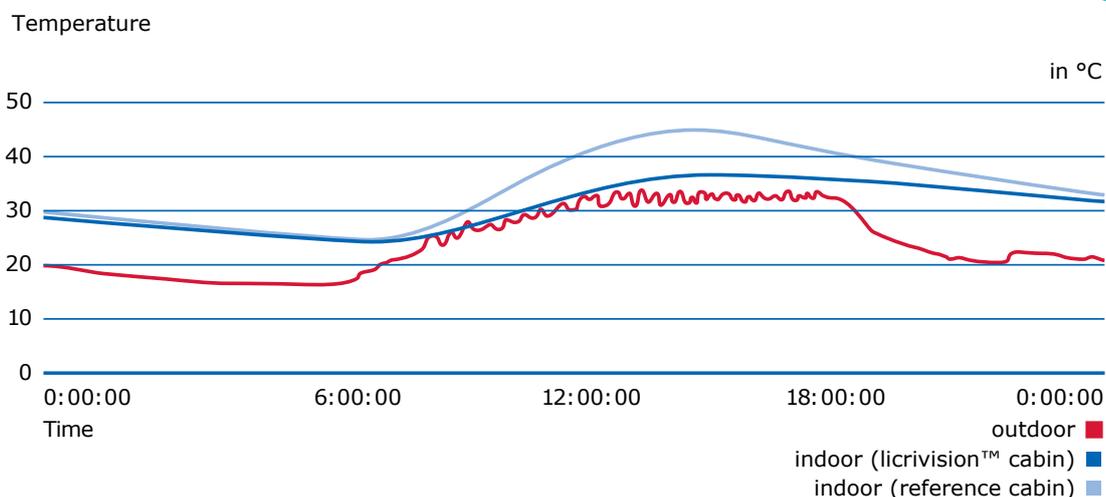
But licrivision™ can do more for you: wherever there is light, there needs to be shade, as applications are not limited to static architecture, allowing new opportunities for trade show booths, mobile structures or in the automotive sector.



ENERGY EFFICIENCY, BEST PERFORMANCE



ENERGY EFFICIENCY AND MAXIMUM PERFORMANCE JOIN FORCES WITH LICRIVISION™, PRESENTING AN EVOLUTION OF GLASS USE IN BUILDINGS



Comparison of temperature in test spaces.
Reference cabin: g -value = 0.44 $T_{vis} = 0.69$ (light transmission),
 $U_g = 1.1 \text{ W/m}^2\text{K}$

The curtain wall is one of the highlights of modernism, but it is also a notorious power drain. Whether in new construction, historic or modern architecture, buildings with generous amounts of glass have issues of energy loss, heat gain and cooling cost.

licrivision™ enhances facade performance in terms of energy efficiency and sustainability by preventing energy loss and controlling solar heat intake with the potential of converting the unused light into electricity. It is valuable for applications in sensitive environments or listed buildings, providing simple, elegant and versatile energy-saving solutions. Cleaning and maintenance is just like taking care of a regular window.



Test set-up at High Tech Campus Eindhoven with licrivision™ cabin (left) versus reference cabin



COST-EFFECTIVENESS BEING AT THE HEART OF THE LIQUID CRYSTAL WINDOW CONCEPT, LICRIVISION™ BALANCES ORIGINAL INVESTMENT AND LONG-TERM BENEFITS THROUGH SPACE AND MATERIAL EFFICIENCY

"Invest now, save later" is a general principle in any construction project. licrivision™ is a high-value solution, providing exceptional visual comfort, views and space at very reasonable cost. Additionally, it reduces capital costs by saving rentable space providing long-term revenue. Original investment in installation increasingly considers that of updating and upgrading existing structures. licrivision™ offers options for easy-to-install "plug-and-play" solutions.

Carrying cost, including ongoing technical care and maintenance, is more important to facility management than ever, which

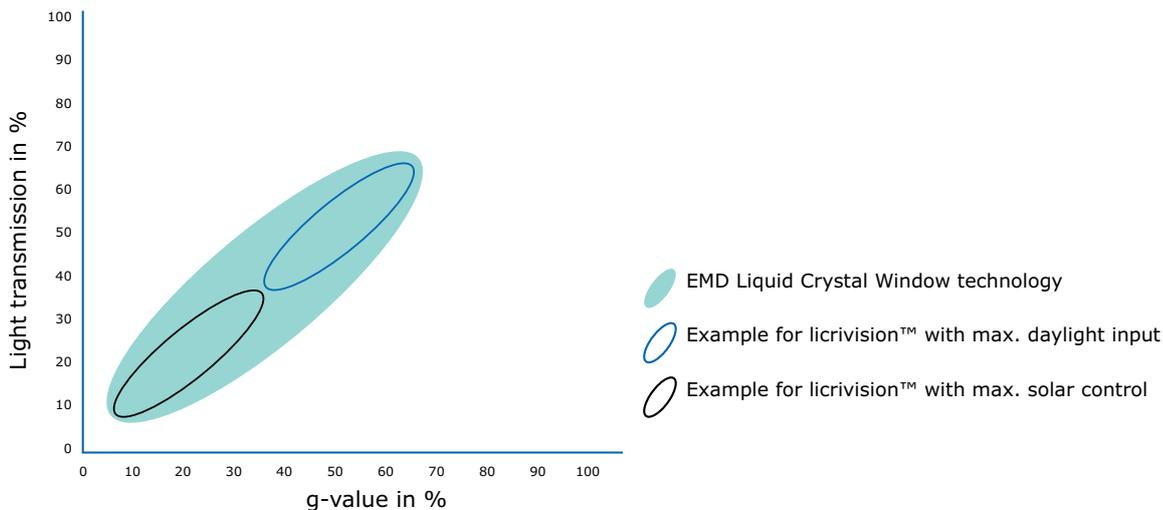
is why licrivision™ is almost self-sustaining. Dedicated to sustainability, it employs fewer material components than conventional solutions and is practically maintenance-free. It is cost-efficient because it reduces heat gains, cooling load and energy loss as well as lifecycle costs.



HIGH VALUE, LOW COST

CONTROLLING LIGHT ON DEMAND

A WINDOW TO THE OUTSIDE WORLD ALSO PROTECTS US FROM IT. LICRIVISION™ REPLACES CONVENTIONAL SUN SHADING WITH FULL FUNCTIONAL CONTROL OVER ALL PRACTICAL NEEDS AND ENVIRONMENTAL CONDITIONS



Light transmission and energy admission values of dynamic switchable windows enabled by licrivision™

Windows equipped with licrivision™ allow for atmospheric changes on demand, with the possibility of dimming and extremely fast and continuously switching options. One touch of a button produces individual settings, while sensor control adjusts to different inside or outside conditions automatically, with central override.

Different dramatic lighting scenarios for interior spaces and interactive facades are some of the sheer endless opportunities for Liquid Crystal Windows with licrivision™. It covers the full range of available solar control glass technology, meeting current glazing standards. The dynamic switching range allows for maximum daylight intake and maximum solar control to ensure well-being.

As with temperature, the line between glow and glare is highly individual, and measuring performance relies on a great number of factors. licrivision™ enables contrast of approximately 1:5 and can brighten up from a 10 percent transmission in the dark state to 50 percent transmission in the bright state. The switching range of LC windows with LCW technology can be tuned in the bright state up to 70* percent or the dark state down to 5* percent.

licrivision™ uses the full spectrum of natural daylight with a 100 percent view outside and neutral color.

*with the equivalent opposite state

INVISIBLE INTEGRATION

NOW YOU SEE IT, NOW YOU DON'T – LICRIVISION™
ADVANCES INVISIBLE INTEGRATION WITH NO MECHANICAL PARTS AND MINIMAL SPACE NEEDS



Building Management System – invisible integration with no mechanical parts and minimal space needs

INVISIBLE INTEGRATION

After their easy installation, smart shading solutions with licrivision™, which are neither seen nor heard, provide plug-and-play shading that is compatible with standard building products for maximum integration. Without additional shading, wiring or mechanical accessories needs, licrivision™ also requires next to no space. It allows for easy detailing, installation and maintenance. Leaving blind boxes, guide rails and wall-mounted controls as well as visual clutter or opaqueness behind, licrivision™ almost invisibly blends into any environment. With no disturbance by electric motor sounds, it basically disappears even when in use.

As simplicity is key for any effective and manageable Building Management System (BMS), licrivision™ seamlessly integrates into any conventional double or

triple Insulated Glazing Unit (IGU) with standard BMS protocols. It is compatible with any standard curtain wall or window framing system in modern and traditional architecture, and is even thinkable for retrofitting. Existing buildings can be turned into innovative buildings without changing their visual appearance, minimizing alterations to the standing fabric.

EXCEPTIONAL DESIGN CHOICE, CONTROL AND INTEGRATION

- Maximize integration with modern and traditional architecture
- Maximize performance with minimal build-up and no visual clutter or opaqueness
- Maximize durability with no mechanical parts subject to wear and tear
- Maximize comfort with easy installation and maintenance
- Maximize flexibility with low-tech adaptive performance, easy-to-install self-powering option and self-responsive sensor units

ADVANCED TECHNOLOGY

WITH INNOVATIVE TECHNOLOGIES, SEEING IS BELIEVING – LICRIVISION™ LETS TECHNICAL FACTS SPEAK FOR THEMSELVES



Liquid Crystal Windows are switchable glass panes with a liquid crystal layer changing light transmission properties in order to control light and heat intake. Specific liquid crystal mixtures containing dyes act as an inter-layer between two glass sheets. licrivision™ is based on liquid crystals typically used in display technology.

Liquid Crystal Windows with licrivision™ can change their permeability for visible daylight and solar radiation through a molecular switching process from bright to dark and vice versa.

FUNCTIONALITY

In windows with licrivision™, the switching process is actuated by conductive layers that are invisibly integrated into the window. The switching occurs instantly, continuously and evenly across the entire surface of the IGU. This switching functionality renders a

static glazing product into a dynamically changing one, adding considerable performance value to the IGU. The autonomous IGU is fitted with a light sensor that can be used as input for the BMS or for individual control. Non-autonomous IGUs have light sensors as an option.

STRUCTURE

Windows with licrivision™ have an integrated UV blocking layer to ensure full functionality and longevity. They have passed UV stability testing according to ISO norms.

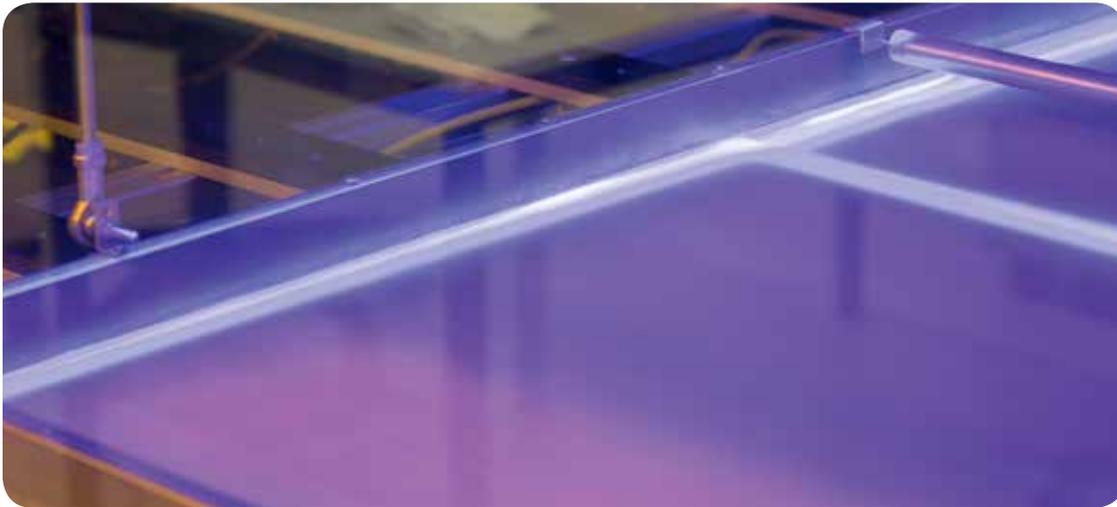
With licrivision™, the quantity of material used for the switchable LC layer is very low. It is indicated that, should a window break, cleaning is straightforward and similar to handling a damaged LCD TV. Materials can be easily separated to allow for unproblematic recycling. Full instructions on handling the product will be provided for commercial products.

LONGEVITY

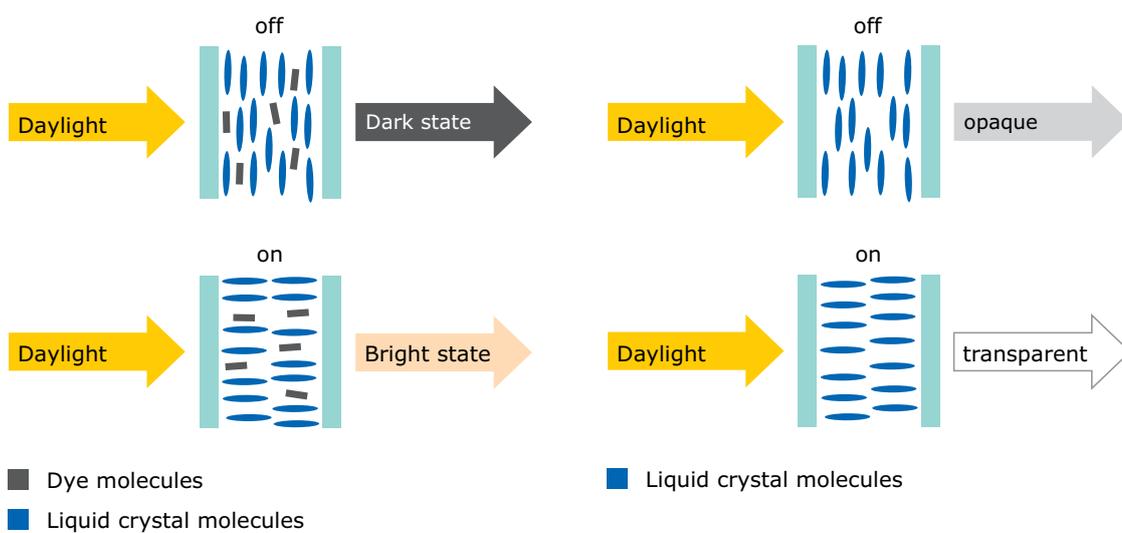
licrivision™ is exceptionally durable, temperature- and UV-resistant and has passed long-term testing according to international norms and standards, without failure or performance deterioration.

We are working on a constant transmission performance of more than 10 years. The product has passed DIN EN ISO-12543 (laminated glass) testing for laminated glazing. Tests with more than one million switching cycles or long-time continuous switching show no change in the product properties. This makes licrivision™ the ideal technology for dynamic applications.

Results of intense one-year tests show that LC windows with licrivision™ can withstand temperatures between -20°C and +100°C, while the liquid crystal material itself has been proven to withstand temperatures in the



range from -40°C to $+120^{\circ}\text{C}$.
 Temperature and humidity tests
 simulating facade conditions are
 ongoing.



In the shading mode licrivision™ works with switchable dyes hosted in liquid crystals (left chart) that change their direction in an electric stress field on demand. Here, liquid crystals function as directors for dyes that will allow more or less radiation to permeate, depending on their alignment, making the window appear darker or brighter. In the private mode (right chart), the liquid crystals change the opacity or transparency of the glass.

OUR COMPANY

MERCK KGAA, DARMSTADT, GERMANY, IS A LEADING COMPANY FOR INNOVATIVE AND TOP-QUALITY HIGH-TECH PRODUCTS IN THE HEALTHCARE, LIFE SCIENCE AND PERFORMANCE MATERIALS SECTORS

Our subsidiaries in Canada and the United States operate under the umbrella brand EMD. We generated total revenues of € 12.8 billion in 2015 with our three business sectors: Healthcare, Life Science and Performance Materials. Around 50,000 employees work in 66 countries to improve the quality of life for patients, to further the success of customers and to help meet global challenges. We are the world's oldest pharmaceutical and chemical company – since 1668, the company has stood for innovation, business success and responsible entrepreneurship. Holding an approximately 70 percent interest, the founding family remains the majority owner of the company to this day.

The advanced LCD materials and high-quality liquid crystal mixtures developed specifically for customers by our laboratories are suitable for turning future applications and ideas into reality. One of these new applications is the Liquid Crystal Window technology, where EMD is the leading material supplier. EMD is driving the technology development and the market introduction together with partners

in the glass, window and facade industry.

Selected examples of the knowledge and innovation that are behind the success of the Performance Materials business and partly the basis for the development of the Liquid Crystal Windows technology are:

DISPLAYS

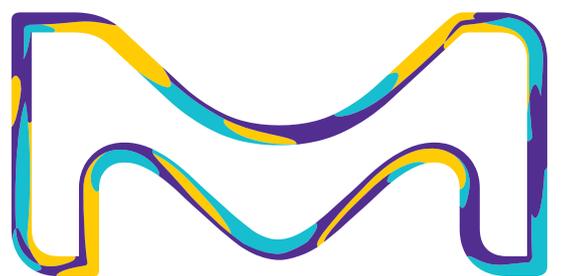
- Performance-optimized, custom-designed and highly reliable LC mixtures for all display modes, such as TN, VA, PS-VA, IPS, FFS
- Reactive mesogen materials for 3D and energy-saving displays
- Cutting-edge R&D in new technologies for the next display generation, such as UB-FFS, Blue Phase and ULH
- High-performance OLED materials for vacuum deposition and printing processes
- Quantum materials for premium color gamut and peak brightness

PHOTOVOLTAICS

- Structuring and process chemicals
- Materials for thin organic solar cells
- Ionic liquids for dye-sensitized solar cells
- Anti-reflective coatings

LIGHTING

- OLED materials
- Advanced phosphor materials for LED light sources



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