

Perfecting devices is key to unlocking metaverse market potential

Advanced Optical and Display-Substrate Technologies Create a Hyper-Realistic Metaverse

Camera, 3D sensing, display substrate, and AR display module technologies optimized for XR devices create realistic virtual presence



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Intro

Extended Reality Technology Creates Hyper-Realistic Virtual Space

The term metaverse has been around for the past 30 years to describe 3D virtual spaces. It became more widely used by the mass media and general consumers in recent years as a result of the pandemic-induced, explosive demand for these spaces. In the absence of physical/social presence, the metaverse quickly took over. Today, the competition to create more immersive, realistic virtual experiences continues to heat up, advancing the metaverse into the realm of extended reality (XR).

XR is an umbrella term encompassing augmented reality (AR), virtual reality (VR), and mixed reality (MR). It is the core technology that is leading the metaverse era. VR replaces reality by creating a completely new 3D digital environment. Meanwhile, AR superimposes digital content onto the real environment as seen through the lens. MR builds a digital world that interacts with the real world seen directly through human eyes, not by the lens. These technologies were initially developed with different purposes, but with metaverse in the spotlight, they are now used in conjunction to create a virtual media environment that is more realistic and immersive than ever.

EXECUTIVE SUMMARY

LG Innotek is taking XR-device performance for the metaverse to the next level with its camera, 3D-sensing, display substrates, and AR display modules.

▶ **Camera modules that collect information on real space and objects**

Recognize the environment such as people, objects, and backgrounds to obtain real world information.

▶ **3D sensing modules that deliver sophisticated three-dimensional effect based on real objects**

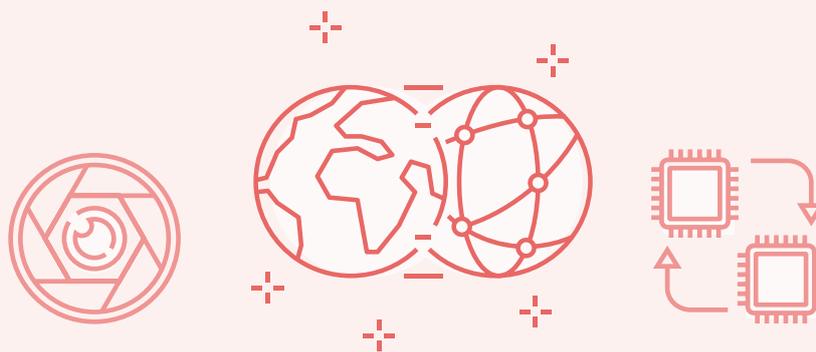
Measure the size, volume, and distance of amorphous objects to create 3D effects in virtual spaces

▶ **Substrates for ultra-thin display for ultra-fine circuits**

Ultra-precision substrate materials that are highly bendable, and offer high circuit integration and flexibility for various parts designs, support ultra-high resolution displays necessary for metaverse devices.

▶ **AR display modules that project augmented reality**

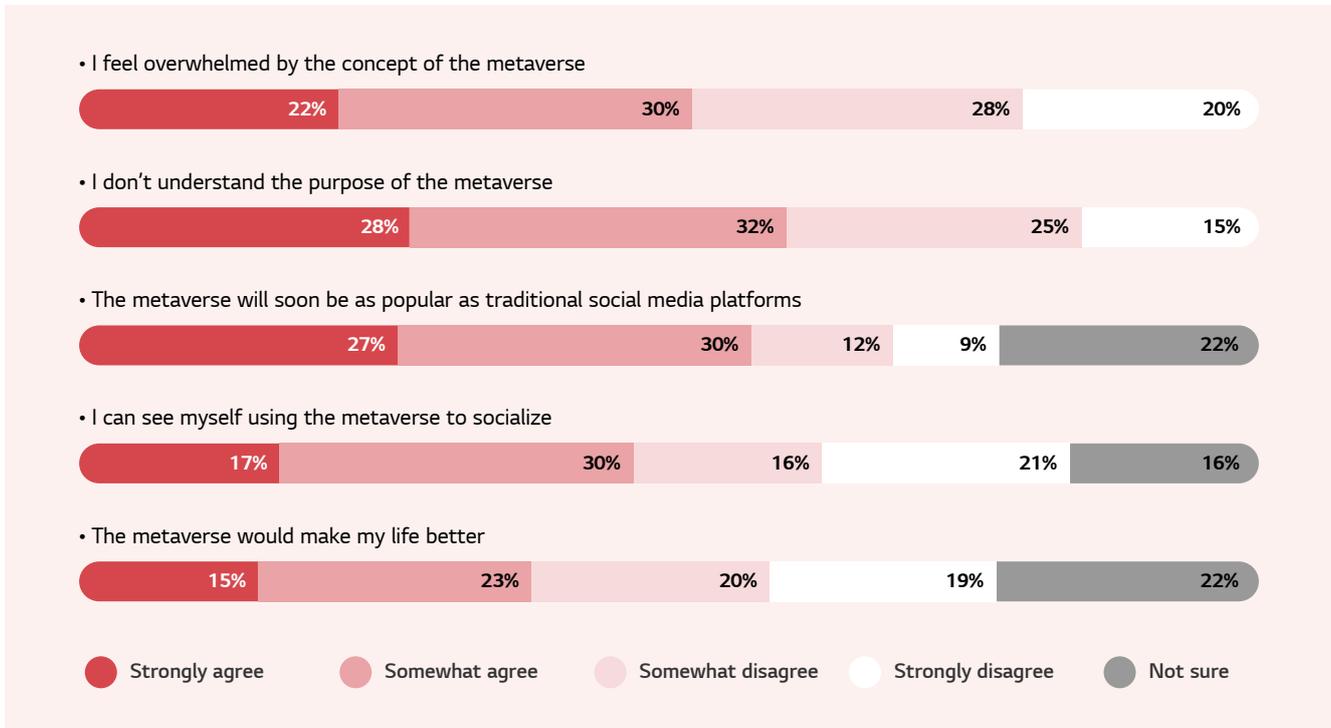
Transmit high-resolution image to a device in the form of glasses, so that the user can see a combined view of real and virtual images.



The metaverse currently lacks the level of reality and immersiveness it needs to appeal to a wider audience. Its human interface service, namely for XR devices, must be perfected—by overcoming the visual fatigue, dizziness, and weight of the device that are causing discomfort for consumers. The interaction between reality and virtual spaces, created by delivering a three-dimensional effect based on real-world object information, as well as projecting digital 3D objects in the real world, also plays an integral role. LG Innotek aims to lead a positive change in the metaverse market with its camera, 3D-sensing, display substrate, and AR display technologies.

As the Internet, smartphones, and social media once did, the metaverse and XR technologies are also going through a transition from "development possibilities" to "widespread use." Market research firm Insider Intelligenceⁱ states that more than half of U.S. consumers over the age of 18 feel overwhelmed by the concept of the metaverse (52%) and don't understand its purpose (60%). At the same time, they expect it will soon be as popular as traditional social media platforms like Facebook, Instagram, and TikTok (57%).

► Attitudes Toward the Metaverse Among U.S. Adults



Source: Insider Intelligence (2022)

In fact, we have already experienced metaverse and XR technologies through various digital services. A case in point is the metaverse concert. Live concerts migrated to virtual stages in the metaverse as large-scale concerts became impossible due to the COVID-19 pandemic. In 2020, 12.3 million simultaneous users flocked to Travis Scott's live concertⁱⁱ held on the virtual stage of a popular metaverse game "Fortnite." The phenomenon continued as top musicians, Ariana Grande and BTS, also followed suit. In March 2022, a Metaverse Fashion Week was heldⁱⁱⁱ on the virtual reality platform "Decentral Land," featuring fashion brands like Dolce & Gabbana.

So far, the metaverse has been focused on specific areas such as games and entertainment. However, as we see more real and virtual spaces connecting through various devices, the metaverse and XR will expand into more diverse areas. In May 2022, Google revealed a prototype of AR glasses that can listen to a live conversation and virtually display the translated speech in real time. Also, Meta introduced a Metaverse-user scenario that is expanded into personal fitness, social networking and business, at its Connect 2021 conference. Meanwhile, consumer research shows that 64% of U.S. consumers already feel comfortable using emerging technologies such as VR, AR, robotics, and artificial intelligence in preventive care and health monitoring^{iv}. The metaverse ecosystem just began to bloom, but will soon expand and deepen into our lives.

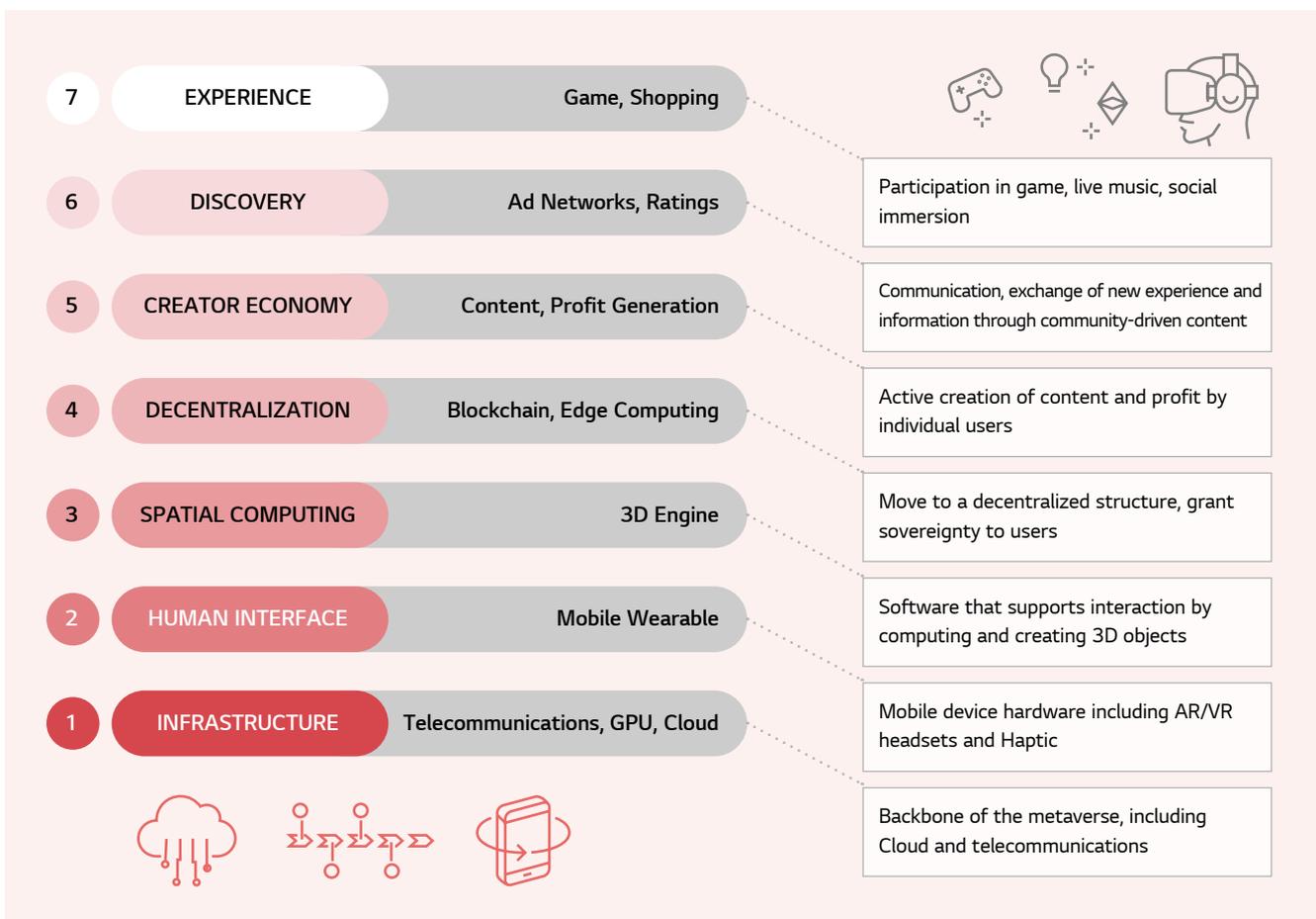
XR Technology Driving Growth of the Metaverse

A competition to preoccupy the metaverse ecosystem

According to Emergen Research, the metaverse-related market is expected to reach USD 828.95 billion by 2028.^v The metaverse has the potential to expand widely and penetrate deeply into consumers' lives.

The seven layers of the metaverse ecosystem^{vi} are expected to affect each other as they continue to develop. Currently, the metaverse market is focused on building human interfaces, including hardware (such as AR and VR headsets), software (such as haptics), as well as the entire ecosystem of content and platforms that interact with them. Applying XR technology to hardware devices and commercializing them is among the initial steps. Perfecting the device, to reach the level of sophistication expected from general consumers, will be key to preoccupying the metaverse market.

► The Seven Layers of the Metaverse



Source: Jon Radoff (2021)

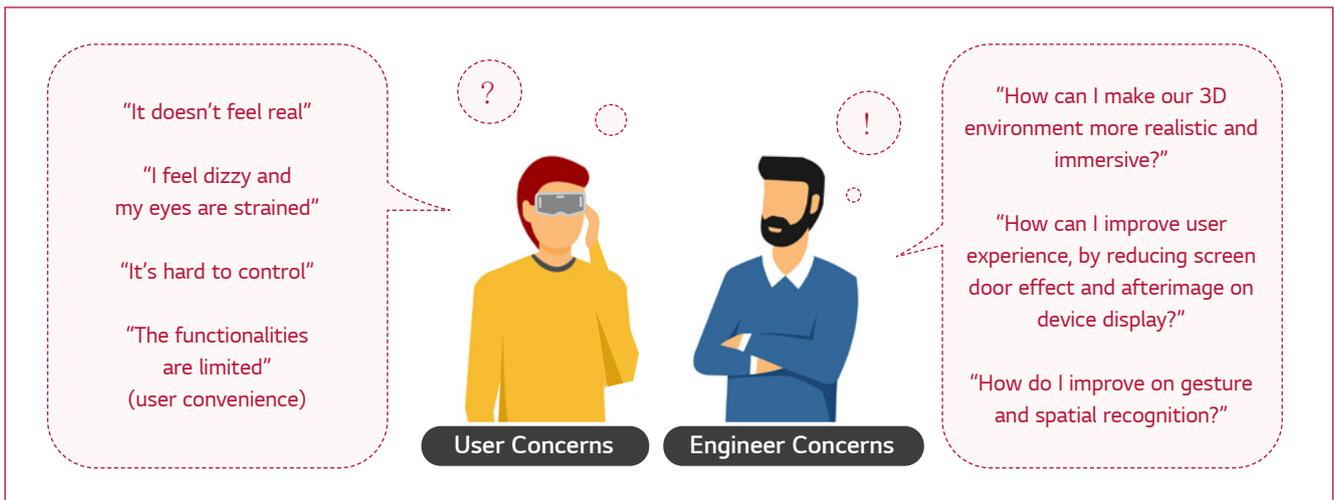
The metaverse has been mostly led by the gaming industry. As the result, VR HMDs (head-mounted displays) for gaming and entertainment currently account for more than 90 percent of XR device shipments. According to a market research firm IDC, the worldwide market for augmented reality and virtual reality headsets grew 92.1% year over year in 2021 with shipments reaching 11.2 million.^{vii} Display industry market research firm DSCC report that VR headset shipments are growing at a CAGR of 34% and is expected to reach 34 million units in 2024.^{viii}

Along with the increase in sales, the range of products is also expanding. Initially, VR devices were mostly connected to PCs and game consoles, but as design, specifications, and functions develop, the standalone devices market is also growing. Among the standalone VR HMD, Meta's Oculus (Oculus Quest 2 is their latest model) has the largest shipment.¹⁸ The AR device market, led by Microsoft's HoloLens (their latest model being HoloLens2), is still in the early stages of growth, but technological advances mean there are now more possibilities for AR smart glasses to make way back into the center stage. Mobile AR technology is also rapidly developing, making it possible for smartphones to create augmented reality without additional devices.

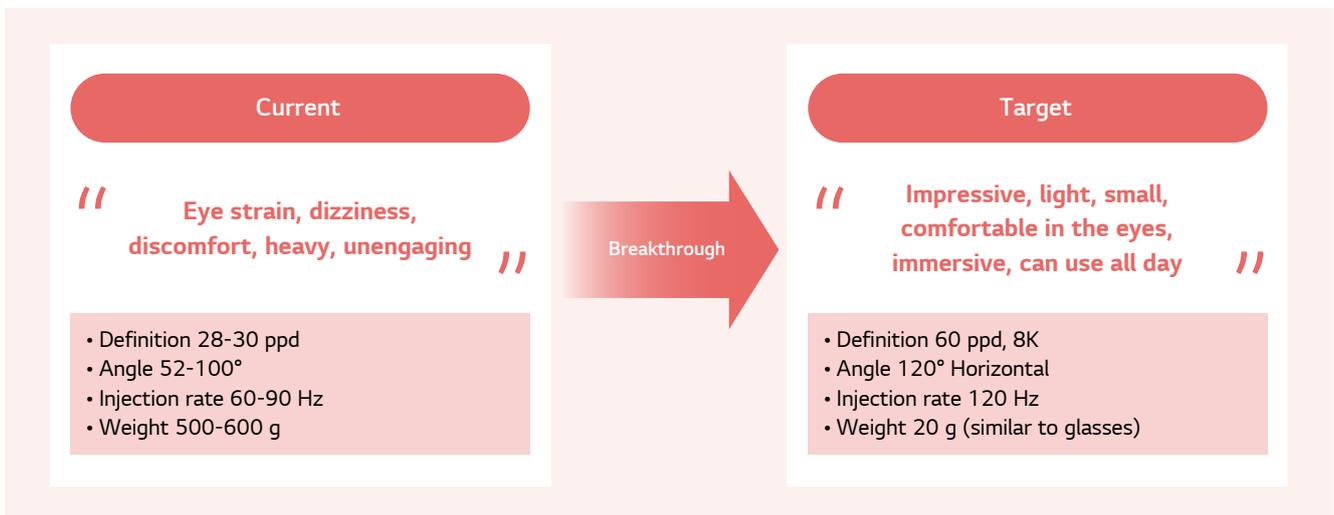
Technical challenges in metaverse device production

The goal of XR metaverse technology is to provide an immersive digital experience that is realer than reality itself. However, there are technical limitations and user inconveniences, such as visual fatigue, dizziness, and heaviness of the device, which have yet to be resolved. As a result, consumers are left with a less immersive environment. For metaverse usage to spread, innovation of VR and AR devices, which solve technical limitations, must come first. Once the devices, which work as the "human interface" into the metaverse, are perfected, this will be an inflection point for metaverse's popularization. XR device developers must look beyond just upgrading the technological specifications and consider how they can improve user experience in various aspects to advance the overall device performance.

► **Technological issues around XR device development**



► **Market Expectations for XR Device Technology**



Above all, camera modules, 3D sensing modules, and substrates for displays are the core elements that contribute to more immersive and realistic experiences. Currently, a number of different technologies are being considered in the XR device market, as the technological standards have yet to be defined.

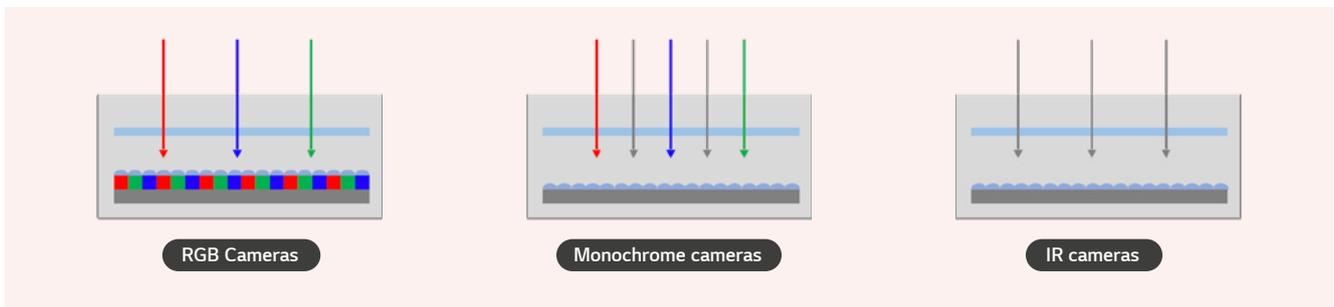
• Camera technology

Camera modules used in XR devices can be divided into RGB cameras to shoot external images and deliver color information, monochrome (black and white) cameras to pinpoint device or user locations, and IR (infrared ray) cameras for eye tracking.

(1) **RGB Cameras:** Apply the same technology as used in regular cameras for smartphones and IoT devices, but prioritize minimizing package sizes optimal to the device's form factor over high-performance or high-pixel.

(2) **Monochrome cameras:** Remove RGB color filters from image sensors to provide high detail and sensitivity regardless of external illumination.

(3) **IR cameras:** Track human eyes used in combination with IR source.

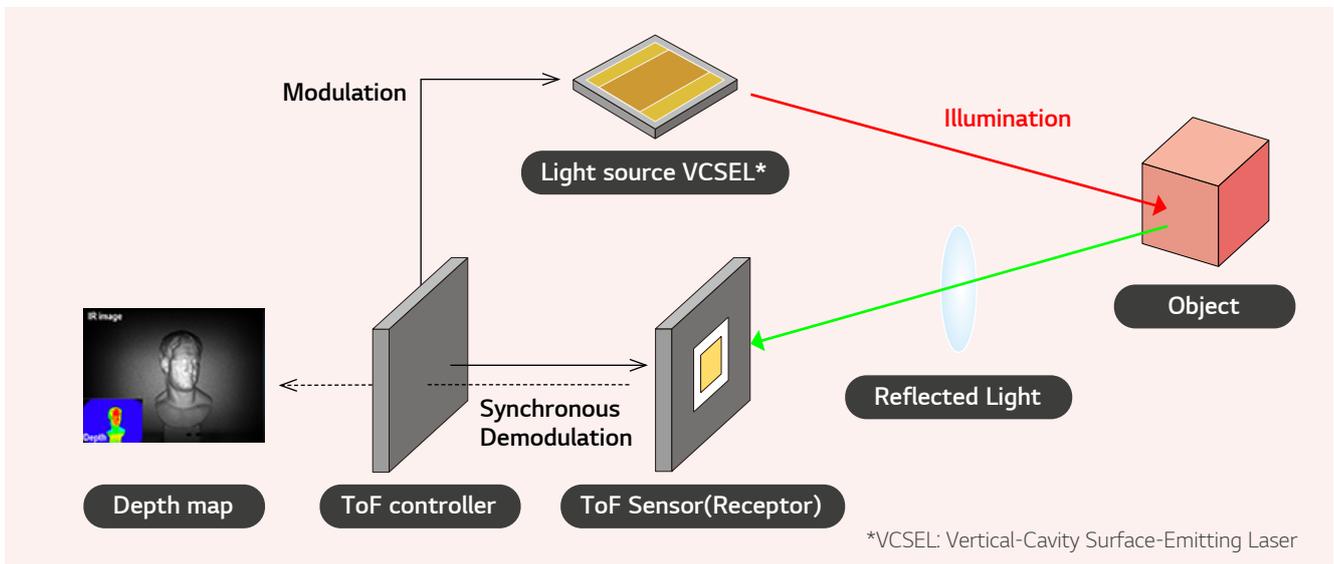


• 3D sensing technology

The metaverse begins with an accurate virtual recreation of real 3D spaces and effects. In order to create an immersive and ambient media environment, however, the 3D sensing module, equipped with Time of Flight (ToF) technology, must be able to accurately sense and deliver three-dimensional images in the same depth that human eyes do. With the use of multiple cameras and 3D sensing modules, the metaverse can be applied in areas beyond XR devices such as drones and robotics.

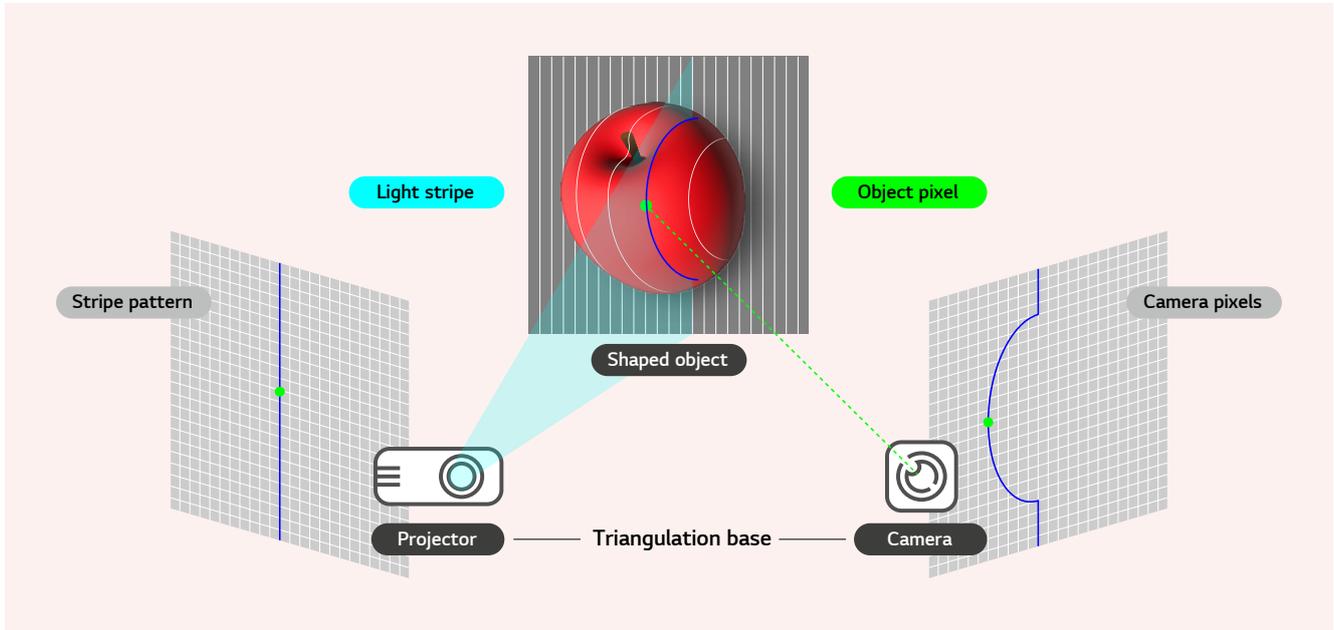
(1) ToF technology

Time of Flight (ToF) technology can measure an object's three-dimensional effect, spatial information, and movement by converting the time it takes for light to bounce off a subject and return. When light is emitted from the light source to the target, the ToF sensor recognizes the return time of the light and measures the distance to the object.



(2) Structured Light technology

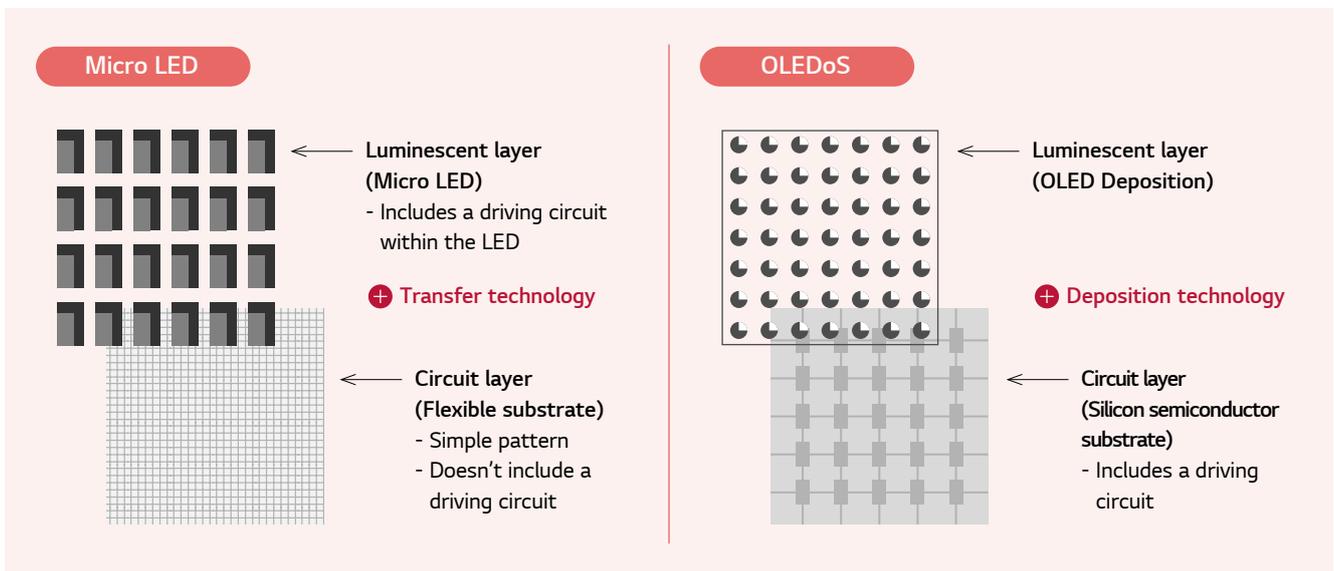
Structural light technology projects patterns (structured light) on the target object to extract information and build a depth map. It analyzes the distortion of the pattern captured by the camera, compared to the original pattern that was projected to the object. Projecting the pattern allows it to measure the distance even when it's difficult to seek out the object. The pattern coding is largely divided into direct, spatial, and temporal codes.



• Micro Display: Micro LED vs. OLEDoS technology

Micro LED uses LED chips 5 to 10 micrometers (μm) thin as light-emitting materials, which can make VR and AR devices lightweight and clear. There are barriers to commercializing Micro LED such as mass-producing micro-LED chips, miniaturizing for high resolution, processing technology such as transfer technology for placing chips onto a substrate, and the overall problem of cost. However, its strength lies in power efficiency, flexible implementation, high resolution, and long life.

OLEDoS use semiconductors as a substrate, unlike other OLEDs that are glass-based, so it can stay thin while accommodating more pixels to create ultra-precision driving layers that can be closely controlled. It allows for implementation of ultra-high resolution with more than 3,000 PPI, enabling fast response speed and high quality.



XR Device Capabilities of LG Innotek

Creating a realistic metaverse requires devices that can accurately input space and 3D effects, and create an immersive environment. LG Innotek is leading the growth of the metaverse market by developing and mass-producing camera, 3D-sensing, display substrate, and AR display modules that are optimized for XR devices.

1. Camera module (RGB, Monochrome, IR Camera)

Based on high-precision alignment technology and optimal module-design capabilities, LG Innotek is developing and mass-producing high-performing and ultra-small camera modules and sensing cameras that can implement various tracking functions.

► LG Innotek Camera Module Technology Features

Best Module Design

Camera module design to deliver optimal performance

- Close partnership with part makers
- R&D units for advanced research of future technologies



Set Level Verification

Advanced research to develop highly reliable products

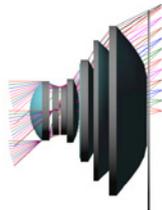
- Phone test and comparison, pre-verification products
 - Standardized evaluation system
- Pre-verification with Android AP
 - Collaborations to implement new applications



In-house Lens Design

Large aperture, Slim TTL, and Wide FoV lens

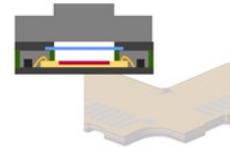
- Capacity to design lens using various materials, such as plastic and glass molds
- Simulation to minimize flare and ghost



Module Package

Slim and thin packaging method

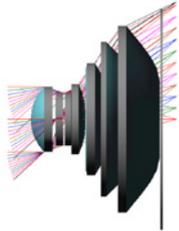
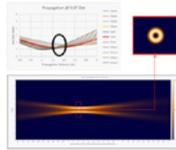
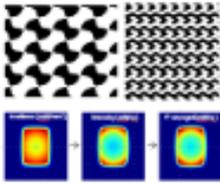
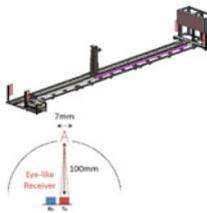
- For small form factor
 - COB(Chip On Board) package based
- For 5G, 4K/8K video



2. 3D sensing module (ToF)

Unlike ordinary cameras, 3D cameras can capture images in 3D and recreate it in a virtual space. 3D sensing based on ToF technology can measure the size and volume of amorphous shapes such as circles and curved surfaces. It can create 3D effects in virtual spaces based on accurate measurements because it is not affected by the brightness of the surroundings and can derive an absolute value rather than a relative one.

► LG Innotek 3D Technology Features

<p>In – House Optics Design</p> <p>Telecentric, Collimation, DOE Solution</p> <ul style="list-style-type: none"> • DOE(Diffractive Optical Elements) & Collimation lens & Diffuser & IR-Lens for ToF • Flare & Ghost simulation 	<p>Manufacturing Process</p> <p>Based on World 1st Mass Production</p> <ul style="list-style-type: none"> • Precise laser to optics, Active Alignment • Laser Compliance Test System for Safety 
<p>Simulation</p> <p>Optimizing design, Safety engineering</p> <ul style="list-style-type: none"> • VCSEL Control/Simulation Expertise • Compact and High Reliability 	<p>Depth Evaluation System</p> <p>Valuable Core Component Characterization Test</p> <ul style="list-style-type: none"> • Calibration/Validation System • Near Field/Far Field Safety System • Precise VCSEL Evaluation 



InnoXensing, our brand specializing in 3D sensing

LG Innotek is a leader in the 3D-sensing market based on its world-class camera-module technology and business know-how. In 2019, LG Innotek launched the 3D-sensing brand “InnoXensing,” leading the 3D-sensing-module market. “InnoXensing” is a combination of the words “innovation,” “X” (from “eXcellent,” “eXtream,” and “eXperience”), and “sensing” from 3D sensing. As the metaverse continues to evolve, LG Innotek will continue to support immersive experiences and inspiring customers with differentiated 3D-sensing technology.

Platformization of 3D Sensing Modules to Create the Metaverse

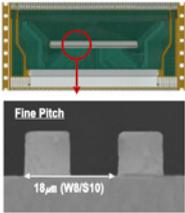
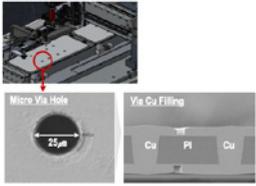
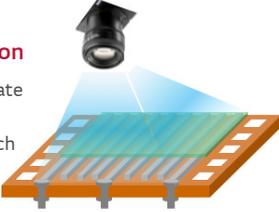
Microsoft and LG Innotek are “platformizing” 3D sensing module to create the metaverse, in response to the growing needs for 3D recognition and implementation across industries. The partnership brings together Microsoft's 3D-recognition software and LG Innotek's 3D-sensing module-manufacturing technology to create a new digital market. The combination of their experience in developing and mass-producing mobile and industrial devices is expected to create further synergy to expand the market.

The partnership will also see Microsoft and LG Innotek working together to find new customers in the 3D-sensing-module business, lifting their profile in diverse areas including global healthcare and distribution. In addition to the B2B metaverse market it currently leads, Microsoft is also planning to further expand into the B2C metaverse market in gaming, which will expand the scope of partnership with LG Innotek in the future.

3. Display substrate (2-Metal COF)

LG Innotek develops and mass-produces ultra-precision substrate materials necessary to run displays based on its world-leading fine-patterning technology. Chip on Film (COF) is an ultra-thin semiconductor substrate that can package and mount a display drive IC, display, and FPCB by forming a microcircuit on a polyimide film. LG Innotek's 2 Metal COF can form micro circuits on both sides of a film and create 4,000 multi-channels within the given space, making it suitable for VR devices that require high circuit directivity. It is also highly bendable and can be folded or rolled despite the high-density circuitry, creating more flexibility in terms of assembly design between different parts of the display. LG Innotek's automatic inspection capabilities for high circuit integration 2 Metal COF also provides a high level of quality and reliability for its customers.

► LG Innotek Display Substrate Technology Features

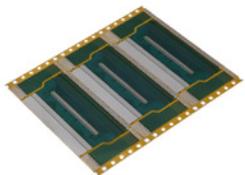
<p>Technology of Ultra Fine Pitch Patterning</p> <ul style="list-style-type: none"> • High quality ultra-fine pitch (18μm pitch↓) • 4,000Ch.↑ multi-channel within limited space 	<p>Technology of Micro Via hole by Laser Drilling</p> <ul style="list-style-type: none"> • World best Laser Drilling capability of micro via hole • High quality micro via hole (25μm↓) • High reliability Via Cu filling 
<p>Technology of High-Resolution Optical Inspection</p> <ul style="list-style-type: none"> • High reliability & quality substrate through Automatic precision inspection capability of fine pitch 	<p>High Flexibility & Miniscule</p> <ul style="list-style-type: none"> • Minimize display bezel through high bending ability • Slimming display module through ultra slim substrate 



Why do XR devices require fine patterning technology?

A display with a high resolution means a display with a large number of pixels. Each COF channel equals one microcircuit and serves to signal one display pixel. Since the number of display pixels is proportional to the number of COF channels (circuits) that carry signals, the size of the channel must be reduced to accommodate many channels in a limited space. LG Innotek's 2 Metal COF provides optimal performance to support ultra-high resolution displays by mounting more than 4,000 micro circuits per unit area on both sides of the film.

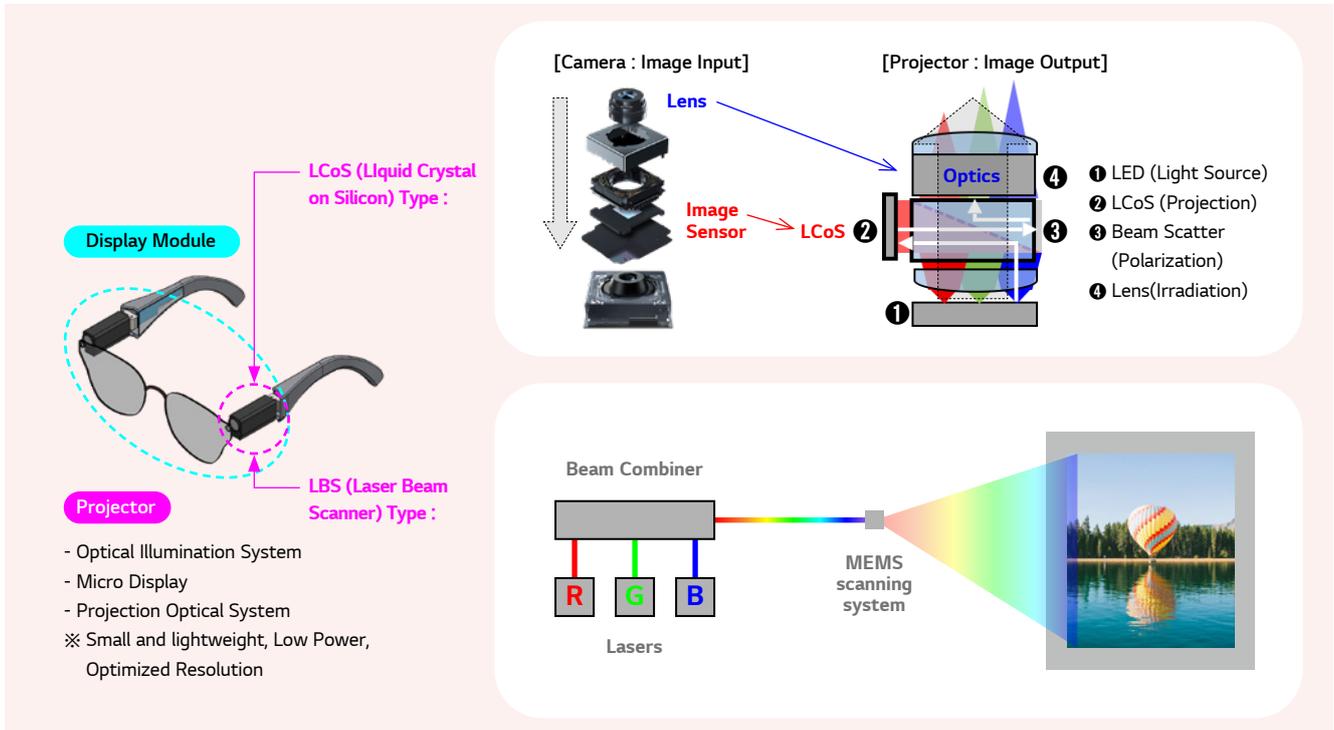
► LG Innotek Metaverse Product Lineup

<p>ToF Module</p> 	<p>Sensing Camera</p> 	<p>Imaging Camera</p> 	<p>2 Metal COF</p> 
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4. AR Display Module

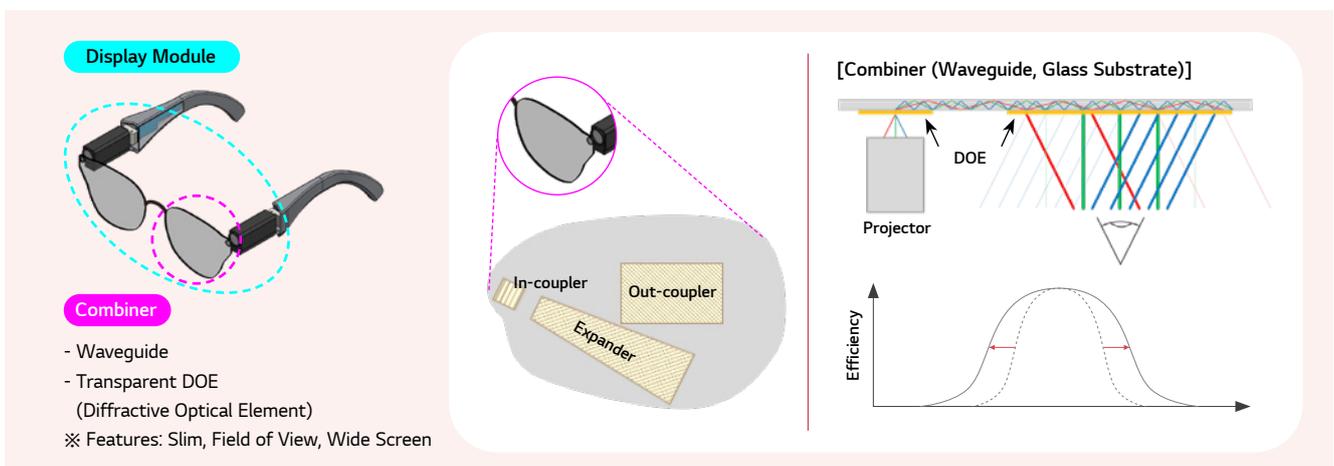
Augmented reality (AR) glasses consist of a projector module that transmits images and a combiner that projects the transmitted images onto the glass screen. The lens and display must be in alignment for the AR-display module to be able to transmit clean images from the projector to the screen. LG Innotek is an expert in alignment technology and has accumulated decades of know-how through its precision camera-module business.

(1) Projector



AR glasses project augmented reality within the user's field of view, which is transmitted from the projector. The glasses must be light enough to be worn for a long time, and designed to be used as an everyday object. Making the projector compact and light is vital, as is delivering the low-energy use and image resolution optimized for AR content. LG Innotek is developing ultra-small AR projectors using its optical-design capabilities and passive/active optical-alignment technology for camera modules.

(2) Combiner



The combiner is a lens that receives the video image from the projector, which should be slim and maintain a wide field-of-view (FoV). LG Innotek is using its expertise in optical design, precision process, and assembly technology to facilitate a wide-angle view in the form of slim and light glasses.

 **Outro**

Until now, the growth of XR device market was impeded by an immature market and poor device performance. However, its user base will grow as we see more content diversification, network innovation through 5G, and the emergence of a large-scale metaverse ecosystem. It is highly likely that XR will grow beyond the current gaming and entertainment industry and expand into the healthcare, education, and manufacturing industries. LG Innotek will continue to help tech companies win the metaverse market as a trustworthy partner with world-leading R&D and production capabilities in optical and display technology.

Reference

- i Insider Intelligence. (2022). The Metaverse. <https://www.emarketer.com/content/the-metaverse>
- ii Variety. (2020). Travis Scott Destroys 'Fortnite' All-Time Record With 12.3 Million Live Viewers. <https://variety.com/2020/digital/news/travis-scott-fortnite-record-viewers-live-1234589033/>
- iii Roblox. (2022). Multi-Platinum Recording Artist 24kGoldn Hosts Virtual Concert on Roblox. <https://corp.roblox.com/2022/03/multi-platinum-recording-artist-24kgoldn-hosts-virtual-concert-roblox/>
- iv Insider Intelligence. (2022). The Metaverse. <https://www.emarketer.com/content/the-metaverse>.
- v Emergen Research. (2021). Metaverse Market Size to Reach USD 828.95 Billion in 2028. <https://www.newsfilecorp.com/release/108102/>
- vi Radoff, J. (2021). The Metaverse Value-Chain. Building the Metaverse. <https://medium.com/building-the-metaverse/the-metaverse-value-chain-afcf9e09e3a7>
- vii IDC. (2022). AR/VR Headset Shipments Grew Dramatically in 2021, Thanks Largely to Meta's Strong Quest 2 Volumes, with Growth Forecast to Continue, According to IDC. <https://www.idc.com/getdoc.jsp?containerId=prUS48969722>
- viii Statista. (2022). Virtual reality (VR) headset unit sales worldwide from 2019 to 2024. <https://www.statista.com/statistics/677096/vr-headsets-worldwide/>
- ix Statista. (2022). Extended reality (XR) headset shipment share worldwide from 1st quarter 2020 to 1st quarter 2021, by brand. <https://www.statista.com/statistics/1222146/xr-headset-shipment-share-worldwide-by-brand/>

About LG Innotek

LG Innotek, Korea's first electronic components company, founded in 1970, has grown into a leading global material and component company by intensely fostering world-class products through continuous technological development and process innovations.

We supply global customers with critical materials and components across the mobile, automotive, display, semiconductor, and IoT industries. Our state-of-the-art global product offerings include smartphone-camera modules, semiconductor substrates for communication, and photomasks for display. In addition, there are also communication module, motor, power, and lighting solutions for vehicles and display and electronic components in the display power/smart-home areas. These products are developed and produced at our business sites, both domestic and abroad.

LG Innotek has established itself as an optimal partner to support customers' business success by applying advanced AI-based digitalization to the entire value chain from product design to production. In addition, our digital twin software enables virtual design and verification of products, while our smart factories increase overall productivity and product quality.

We will achieve our vision of becoming the No.1 global material and component company through meaningful and unique technological innovation and convergence.

With its headquarters in Seoul, LG Innotek has sales subsidiaries in Germany, the United States, China, Japan and Taiwan, and production subsidiaries in China, Vietnam, Indonesia, Mexico and Poland.

More information can be found on our website (www.lginnotek.com)



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