

DISPLAYS AND OPTICS FOR AR & VR 2020

Market & Technology Report - April 2020

Optics are getting ready - now MicroLED displays are the next roadblock for the implementation of augmented reality.

WHAT'S NEW

- Technology status and trends
- Bill of materials approach to consumer trends; how to trade off on technology to enable a compelling headset
- Shipment volumes and values for displays and optics in headsets
- Use cases: What is there for the consumer and what should be there? What is the role of OEMs?
- Supply chain and industry establishment

KEY FEATURES

- Analysis of key challenges related to AR & VR systems
- Technical analysis of displays and optics for AR & VR, and associated roadmaps
- Analysis of related industrial and technological ecosystems
- Market analysis/forecast for displays and optics
- Analysis of future trends and evolution of AR & VR market landscapes

REPORT OBJECTIVES

Understand the status of displays and optics technologies in AR & VR:

- Recent progress
- What are the remaining pinch points?
- What are the trade-offs that will drive adoption? Status, trends and roadmaps for consumer adoption

Competitive landscape and supply chain:

- Identify the key players in technology development and manufacturing. Who is taking the lead? Key partnerships
- Scenarios and impacts for the supply chain

Market insights:

- AR & VR numbers of headsets
- Subsequent volume and value for displays and optics
- Focus on waveguides and microdisplays, enabling the transition towards consumers

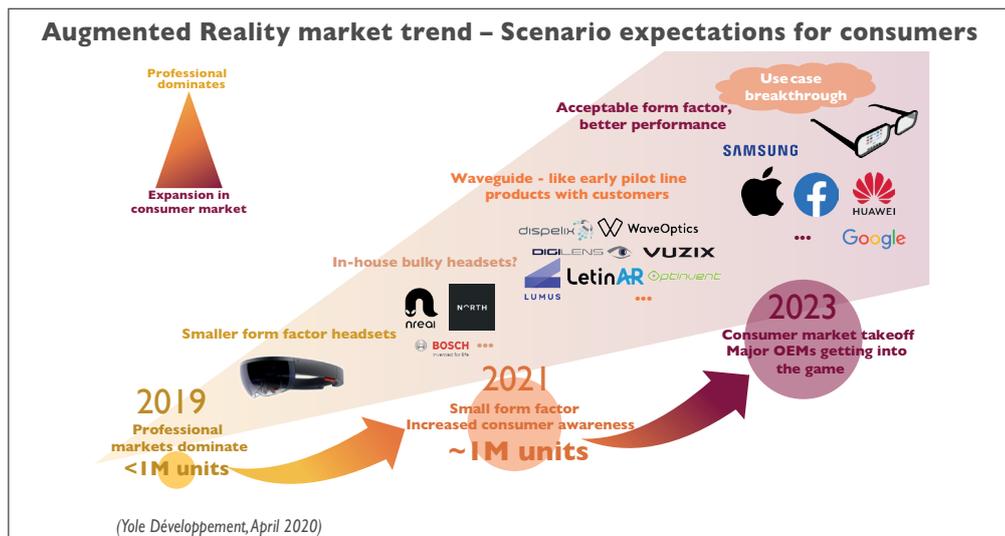
TECHNOLOGICAL DEVELOPMENTS BRING A BRIGHTER FUTURE

Augmented Reality (AR) and Virtual Reality (VR) have been hot topics for decades. VR has been around for the consumer for some years now, built upon off-the-shelf components. Apart from general improvements, the form factor is being worked upon and we see many developments in microdisplays, including OLED-on-Silicon and microLEDs, alongside pancake optics to be able to deliver a proper pixel density, field of view and form factor.

AR was and continues to be the dream consumer electronics companies want to make real to deliver the long-awaited revolution of replacing smartphones. But as children of the flat panel display industry, we are used to having very high-quality displays all around us. And the image quality that AR has been able to provide so far is not at this level yet. But technology has been improving on all fronts and we are seeing some progress in waveguiding optics and microLEDs that will bring new functionality.

Yole Développement's analysts expect a first generation of headsets to come in soon with a 2021 milestone for reaching a significant volume sold. These will be based on conventional optics

with most likely either MEMS or OLED-on-Silicon display solutions. However, for the market to really be enabled, a complete technological paradigm shift is required. In terms of optics, everything revolves around waveguiding technology. For a long time they have been improving and were fighting against the poor optical efficiency they could deliver. From less than 1% efficiency we can now see results that go an order of magnitude beyond that. So much so that, while uniformity needs to be improved, they meet the minimum requirements for Original Equipment Manufacturers (OEMs). Yole Développement (Yole) expects a second milestone around 2023 when the big consumer electronics brands come in with a product that respects the consumer requirement trio of performance, cost and form factor. But one element is still missing at the moment: the display engine. Though efforts are continuing, we have not seen a microLED product yet. MicroLED microdisplays can provide what the other solutions cannot, including brightness, form factor, color and contrast. And all the OEMs are waiting for this opportunity to materialize, as we anticipate its penetration to reach 30% by 2027.



AN EMERGING SUPPLY CHAIN WITH KEY MANUFACTURING CHALLENGES

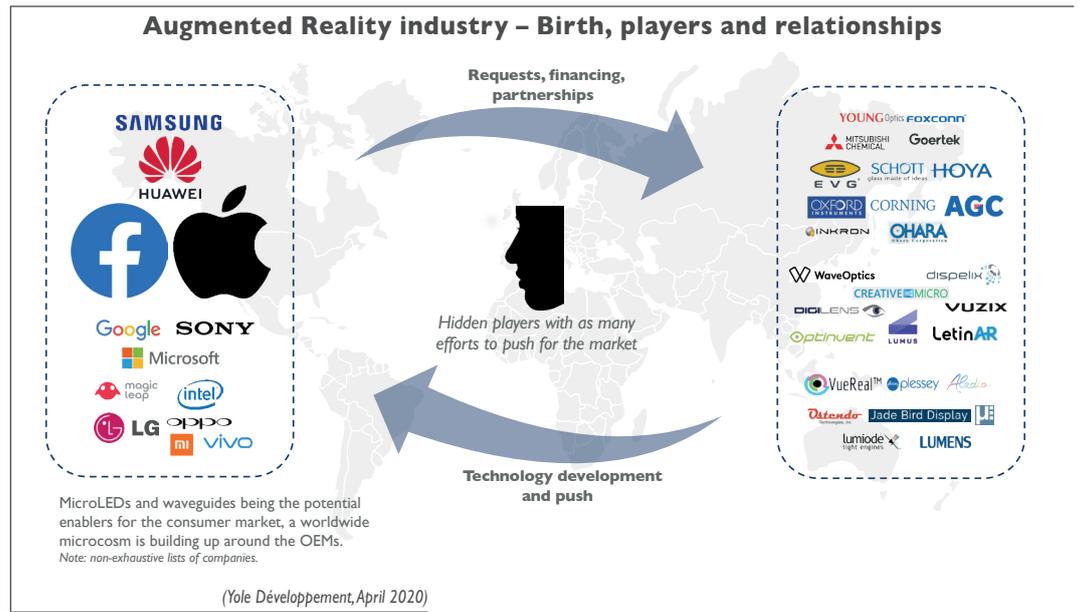
As it is complex to manufacture a microLED microdisplay at an acceptable cost with a proper level of performance, we can monitor the industry's progress. Many prototypes have been shown over the past 24 months, with different manufacturing paths including red/green/blue (RGB) native colors, color conversion

and hybrid bonding. In late March 2020, the Plessey and Vuzix partnership for microLEDs in AR came to an end when Facebook signed an exclusivity deal for Plessey to supply them with microLEDs. This illustrates the interest in the technology and how the supply chain is establishing itself.

In the meantime, we have seen lots of movement from the waveguiding optics perspective. In the past few years, we have seen investments and partnerships including Lumus with Quanta, Digilens with Foxconn, WaveOptics with Goertek and Apple with Akonia. Between reflective, diffractive and holographic waveguides, comes the question of who is going to get the lion's share. It will all come down to performance and cost. And cost is very much linked to the manufacturing paths taken by the different technologies. Surface-relief grating-based waveguides have been well-known for years now, being the choice of Microsoft or Magic Leap. But poor yields linked to

a complex manufacturing process based on nano-imprint lithography led to high costs. This has been improved and now WaveOptics or Dispelix can likely provide waveguides to any OEM, moving from a captive technology towards becoming openly available.

Among Apple, Facebook, Huawei and Samsung, who shall be the first to deliver a sleek design, good performance and decent cost consumer headset? There is little to no doubt that though Apple has everything in-house, all major brands are close and establishing partnerships and deals with all the waveguide and microLED players to reach the consumer.

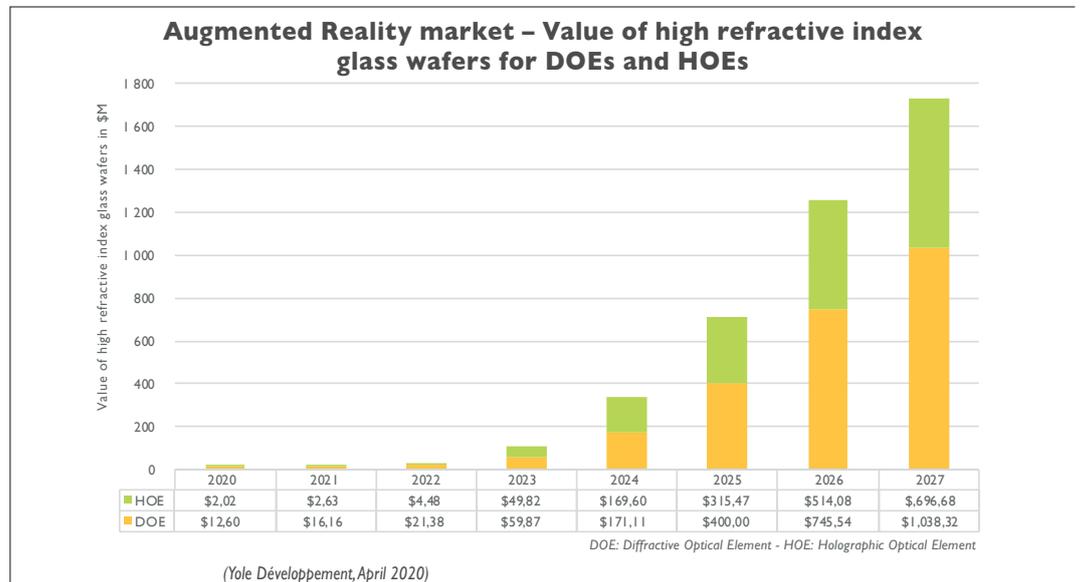


THE NUMBERS OF THE CONSUMER MARKET DREAM

The AR market has been mostly a professional-based market, as the performance, cost and form factor trio is hard to balance. But thanks to all the technological advancements, we can expect a 105% Compound Annual Growth Rate (CAGR) through to 2027 in volume for AR headsets. And this promise of a strongly growing market has sparked

the interest of many in the supply chain, some still in stealth mode.

Waveguides have improved a lot thanks to design efforts but also thanks to the push from equipment makers intensifying their efforts such as EV Group and Oxford Instruments and substrate manufacturers.



The glass industry has been working at providing high refractive index wafers to allow for waveguide manufacturing, trying to push and enable the market. Given the projected wafer numbers and associated revenues, were the consumer market to thrive, it would represent a non-negligible part of even the enormous glass business.

But for the consumer market to thrive, it is about more than just the hardware and providing a high-quality image in something that looks like a regular pair of glasses. If the end-result simply consists of putting a smartwatch screen in front of the eye, this is probably not compelling enough. Much like VR, there is a need for a real

disruption in the use case. That is why we expect the OEMs to come in with a proper proposition to really kickstart the market. As the history of the smartwatch shows, we think the adoption curve for AR will follow the same path, with first early products maybe not providing compelling performance and use case, until a big gun jumps in. As an example, Apple seems like a good candidate for that: they have the microLED effort, the waveguide effort, the application effort with ARKit and also the 3D sensing effort. As they progressively integrate some of these technologies in their newer products, they can raise awareness about AR, preparing the consumer for when everything is ready for a headset. And perhaps we'll see that by 2023.

COMPANIES CITED IN THE REPORT (non exhaustive list)

4th Dimension Displays, AGC, Akonia Holographics, Aledia, Apple, AUO, Avegant, Bayer, BOE, Bosch, Canon, CastAR, Ceres Holographics, Colour Holographic, Compound Photonics, Corning, Daqri, Dell, Digilens, Dispelix, eMagin, Etri, EVG, Eyefluence, Facebook, Finisar, Fove, Fraunhofer, Glo, Google, Hamamatsu, Himax, Holoeye, Hoya, HP, HTC, Idealens, Inkron, Intel, ITRI, Jade Bird Display, JDI, Jorjin, Konica Minolta, Kopin, Leap Motion, Lenovo, LetinAR, LG, Limbak, Linq, LiteON, Luminix, Lumiod, Lumus, Magic Leap, Meta, Miledi, MicroOLED, Microsoft, Mira, Molecular Imprints, Nintendo, North, Nreal, Nvidia, Oakley, Oculus, Ohara, Olightek, Optinvent, Ostendo, Osterhout Design Group, Oxford Instruments, Pico, Pimax, PlayNitride, Plessey Semiconductors, Pupil Labs, Qualcomm, Raontech, Razer, Rockwell Collins, Samsung, Schott, Sega, Seiko Epson, Sony, Starbreeze, Sumita, Syndiant, Texas Instruments, Tooz, Valve, Varjo, Vuzix, WaveOptics, Young Optics and more.

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ABOUT YOLE DEVELOPPEMENT

Founded in 1998, Yole Développement (Yole) has grown to become a group of companies providing marketing, technology and strategy consulting, media and corporate finance services, reverse engineering and reverse costing services. With a strong focus on emerging applications using silicon and/or micro manufacturing, the Yole group of companies has expanded to include more than 120 collaborators worldwide covering MEMS and Image Sensors, Compound Semiconductors, RF Electronics, Solid-state Lighting, Displays, Software, Optoelectronics, Microfluidics & Medical, Advanced Packaging, Manufacturing, Power Electronics, Batteries & Energy Management and Memory.

The “More than Moore” market research, technology and strategy consulting company Yole Développement, along with its partners System Plus Consulting, PISEO and Blumorpho, supports industrial companies, investors and R&D organizations worldwide to help them understand markets and follow technology trends to grow their business.

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- Market data & research, marketing analysis
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2.2 The Seller shall by no means be responsible for any delay pursuant to Article 2.1 above, in particular in cases where a new event or access to new contradictory information would require the Seller analyst to dedicate extra time to compute or compare the data in order to enable the Seller to deliver a high quality Product.

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2.6 No return of Products shall be accepted without prior written notification from the Buyer to the Seller, even in case of delayed delivery. Any Product returned to the Seller without the Buyer providing prior notification to the Seller as required under Article 2.5 above shall remain at the Buyer’s risk. In no event shall the Seller incur any liability for Products erroneously ordered by the Buyer, or for any request from the Buyer to replace a Product previously ordered by a different Product.

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HSBC, 1 place de la Bourse 69002 Lyon France
Bank code: 30056
Branch code: 00170
Account n°: 0170 200 1565 87
BIC or SWIFT code: CCFRFRPP
IBAN: FR76 3005 6001 7001 7020 0156 587

To secure the payments due to the Seller, the Seller reserves the right to request down payments from the Buyer. In such case, the need for a down payment will be mentioned on the corresponding order.

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4.1 The Buyer or any other individual or legal person acting on its behalf, being a business user buying the Products for its business activities, shall be solely responsible for the choice of the Products purchased as well as for the use and interpretations the Buyer makes of the documents it purchases, of the results the Buyer obtains, and of the advice and acts the Buyer bases thereon .

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