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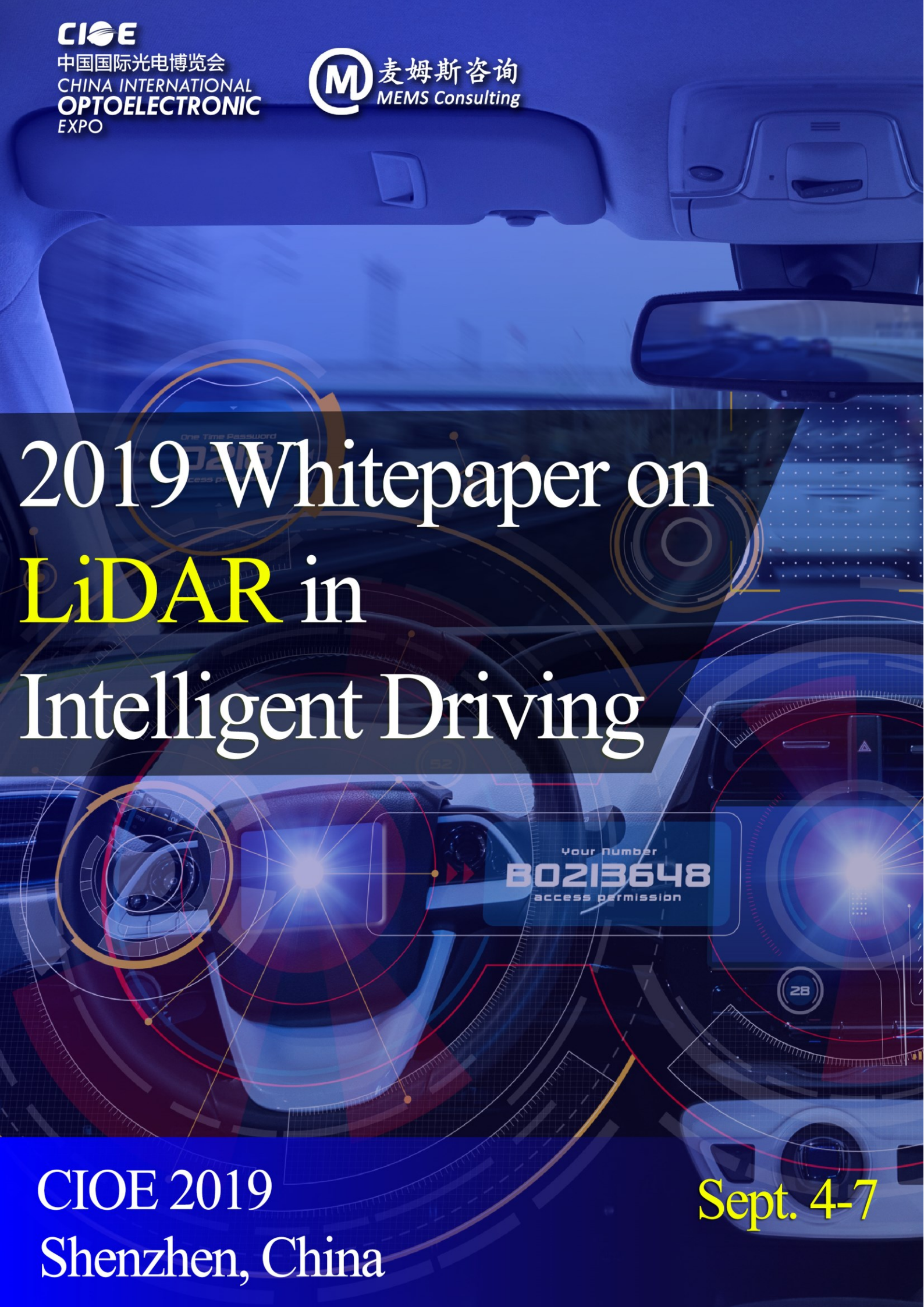

2019 Whitepaper on LiDAR in Intelligent Driving

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目录 Content

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第一部分：调查背景 1. Background

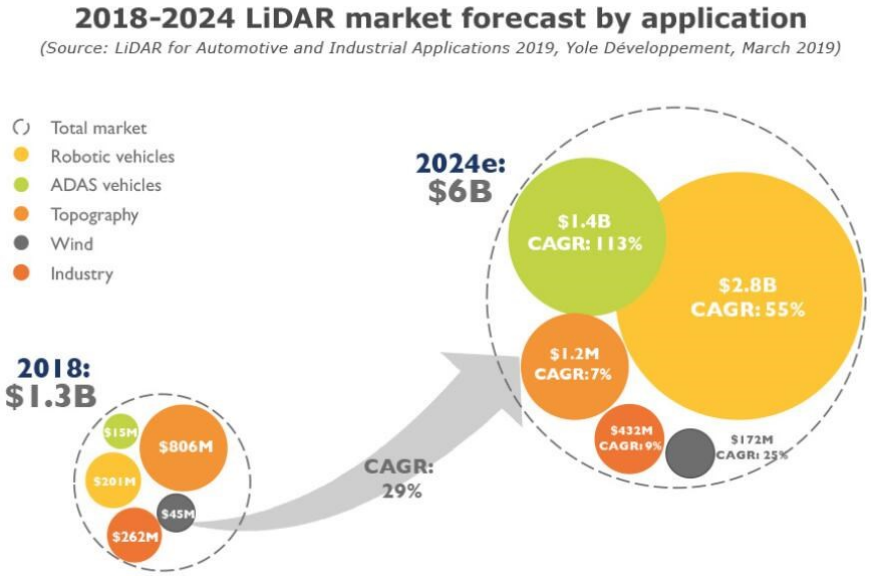
最近，智能驾驶激光雷达行业可谓热闹非凡。一方面，激光雷达领域的投资热潮热度不减。今年 3 月，MEMS 激光雷达厂商 Innoviz Technologies（与宝马合作，计划在 2021 年将 MEMS 激光雷达集成于汽车）宣布完成 C 轮共计 1.32 亿美元的融资，投资方来自以色列投资机构哈雷尔保险（Harel Insurance Investments and Financial Services）和凤凰保险（Phoenix Insurance Company)，中国招商局资本、深创投和联新资本。据麦姆斯咨询介绍，从 2016 年以来，激光雷达行业的投资已经超过了 10 亿美元。另一方面，激光雷达因为价格昂贵、技术成熟度在短期内无法完全满足智能驾驶的需求而饱受争议，特斯拉（Tesla）首席执行官马斯克最近则公开 diss 所有使用激光雷达的自动驾驶公司，说用激光雷达真是“荒唐”，他们“注定失败”！

Recently, the intelligent driving LiDAR industry has been in a full swing. On the one hand, the investment boom in LiDAR industry continues unabated. In march, Innoviz Technologies, a manufacturer of MEMS LiDAR, (in partnership with BMW, plans to integrate MEMS LiDAR into cars by 2021)announced the completion of a $132 million series C financing round from Harel Insurance Investments and Financial Services, an Israeli investment firm and Phoenix Insurance Company, CMC capital, Shenzhen Capital Groupd and New Alliance Capital. Since 2016, investments in the LiDAR industry have exceeded $1 billion, according to MEMS consulting, on the other hand, is under controversy in view of its expensive price and technical maturity can not fully meet the needs of intelligent driving in the short term. Tesla CEO Elon Musk recently publicly made a statement on all companies using LiDAR automatic driving, said it was "ridiculous" to use LiDAR and they are "doomed"!

而另一方面，在 Yole 最新发布的报告《汽车和工业应用的激光雷达-2019 版》中预测，到 2021 年自动驾驶汽车的总量将达到 44000 辆。与此同时，激光雷达市场也因此受益，预计将从 2018 年的 13 亿美元增长到 2024 年的 60 亿美元。令人振奋的是，汽车应用占据激光雷达市场的 70%份额！

On the other hand, Yole's latest report, *LiDAR for automotive and industrial applications 2019*, predicts that the total number of

autonomous vehicles will reach 44,000 by 2021. The LiDAR market, meanwhile, is expected to grow from $1.3 billion in 2018 to $6 billion in 2024.The exciting thing is that automotive applications account for 70% of the LiDAR market!



2018-2024 LiDAR market forecast by application

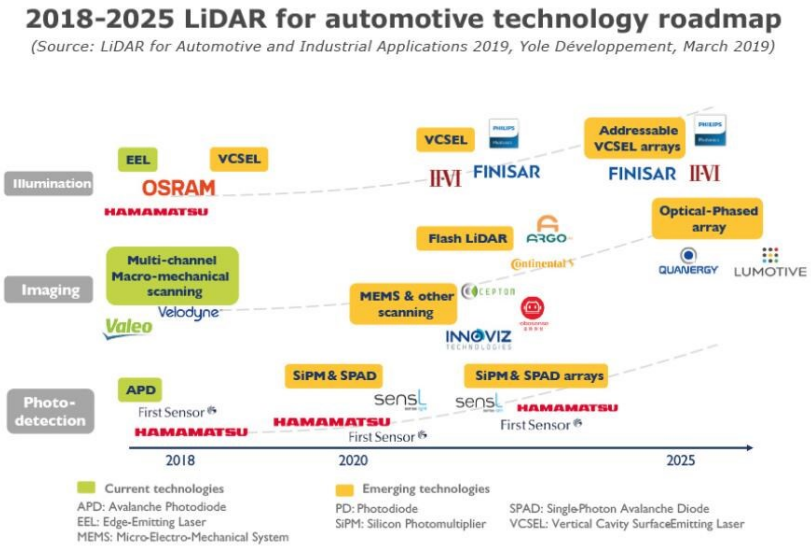
关于不同激光雷达技术路线，目前业界大多数声音是采用 MEMS 微镜实现光束扫描的激光雷达是最快落地的固态技术，麦姆斯咨询曾在《2019 年会成为 MEMS 激光雷达技术路线元年吗？》中对该技术路线做了较为详细的分析；而 Flash 激光雷达虽然暂时无法兼具远近距离探测，但是作为没有任何运动部件的技术路线，在大陆集团的引领下，也有望看到成熟产品；光学相控阵（OPA）激光雷达如果能突破 OPA 芯片技术制造壁垒，前景可期，并且近期看到的以 MEMS 技术实现大阵列 OPA 或许会成为未来方向。当然，也许未来的主流激光雷达并非出自以上技术路线。比如 Lumotive 提出一种超材料的“关键技术”，基于超材料的光弯曲特性，Lumotive 液晶超表面芯片可以不依赖传统机械式激光雷达中的旋转部件，而操纵激光束的偏转。

As for different LiDAR technology routes, at present, most voices in the industry are that using MEMS scanning mirror to realize beam scanning is the fastest available solid-state technology. The technical route is analyzed in detail by MEMS Consulting in *Will 2019 be the first year of MEMS LiDAR technology?* Although Flash LiDAR is not able to detect near and far at the moment, it is expected to see mature products under the guidance of mainland group as a technical route without any

moving parts. Optical phased array (OPA) LiDAR has a promising future if it can break through the manufacturing barrier of OPA chip technology, and the implementation of large array OPA by MEMS technology recently may become the future direction. Of course, perhaps the mainstream LiDAR of the future will not come from the above technological route. Lumotive, for example, has come up with a "key technology" for metamaterials based on the bending properties of metamaterials, its liquid crystal metasurface chip can manipulate the deflection of a laser beam without relying on rotating parts in traditional mechanical LiDAR.

激光雷达在满足车规级的奋斗路途上，也带领了整个产业链的共同进步。除了上述光束操纵元器件，光源和光电探测器厂商也紧密合作以推动车载激光雷达的尽快落地。麦姆斯咨询在最新发布的《激光雷达技术及核心元器件-2019 版》中对相关核心元器件技术及产业链进行了详细的分析，例如：905nm 边发射激光器（EEL）是当前主流激光器，但 1550nm 光纤激光器和垂直腔面发射激光器（VCSEL）阵列厂商也在体积、性能和成本上继续改进。光电探测器方面，雪崩光电二极管（APD）阵列是最成熟和常见的器件，而单光子雪崩二极管（SPAD）和硅光电倍增管（SiPM）也有采用并被视为将来的主流光电探测器。

LiDAR also leads the progress of the whole industrial chain in the struggle to meet the requirements of vehicle regulation. In addition to the above beam control components, the light source and optical detector manufacturers also work closely to promote the landing of onboard LiDAR as soon as possible. MEMS Consulting in the latest release of *the LiDAR technology and core components - 2019 edition* analyzed the core components of related technology and the industry chain in detail, for example: 905 nm edge emitting laser (EEL) is the current mainstream laser, but the 1550 nm fiber laser and the vertical cavity surface emitting laser (VCSEL) array vendors also continues to improve on size, performance and cost. As for optical detectors, avalanche photodiode (APD) arrays are the most mature and common devices, while single-photon avalanche diode (SPAD) and silicon photomultiplier tube (SiPM) are also adopted and considered as the mainstream detectors in the future.



2018~2025 LiDAR for automotive technology roadmap

为了推动激光雷达行业的发展以及充分了解目前该行业发展中面临的机遇和挑战，CIOE 中国光博会联手麦姆斯咨询进行《智能驾驶激光雷达行业白皮书》调研，内容涵盖激光雷达市场趋势、技术方案等。本次调查历时 20 个自然日，共获得 1224 份有效问卷。受调查者主要来自整车厂、激光雷达厂商、激光雷达核心元器件厂商（如光电探测器、激光器、MEMS 微镜、透镜等）、自动驾驶系统及解决方案商。

In order to promote the development of LiDAR industry and fully understand the opportunities and challenges in the development of this industry, CIOE China International Optoelectronic Exposition and MEMS Consulting conducted a research on *intelligent driving LiDAR industry white paper*, covering the market trends and technical solutions of LiDAR. The survey lasted 20 natural days, and a total of 1224 valid questionnaires were obtained. Respondents mainly come from vehicle manufacturers, LiDAR manufacturers, LiDAR core components manufacturers (such as photodetector, laser, MEMS scanning mirror, lens, etc.), automatic driving system and solution manufacturers.

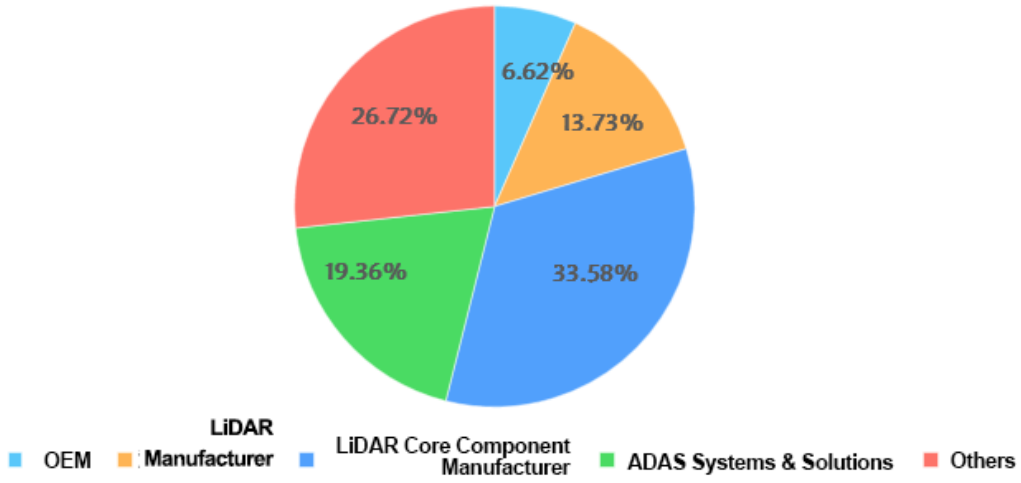
1.1 受调查者分析 Respondent Analysis

我们的调查对象来自整车厂、激光雷达厂商、激光雷达核心元器件厂商（如探测器、激光器、MEMS 微镜、透镜等）、自动驾驶系统及解决方案商，以及其它类型厂商。

其中，来自激光雷达核心元器件厂商的受调查者比例最高，占所有受调查者的 33.58%；来自 19.36%的受调查者来自自动驾驶系统及解决方案商；真正来自激光雷达厂商的受调查者比例仅 13.73%；此外，参与调查的对象有 6.62%来自整车厂，26.72%来自其它类型厂商。

Our survey subjects come from vehicle manufacturers, LiDAR manufacturers, LiDAR core components manufacturers (such as detectors, lasers, MEMS scanning mirrors, lenses, etc.), autonomous driving system and solution manufacturers, and other manufacturers.

Among them, the percentage of respondents from core components manufacturers of LiDAR is the highest, accounting for 33.58%.19.36% of the respondents are from autonomous driving system and solution providers; Only 13.73% of the respondents were from LiDAR manufacturers. In addition, 6.62% of respondents are from OEMS and 26.72% from other manufacturers.

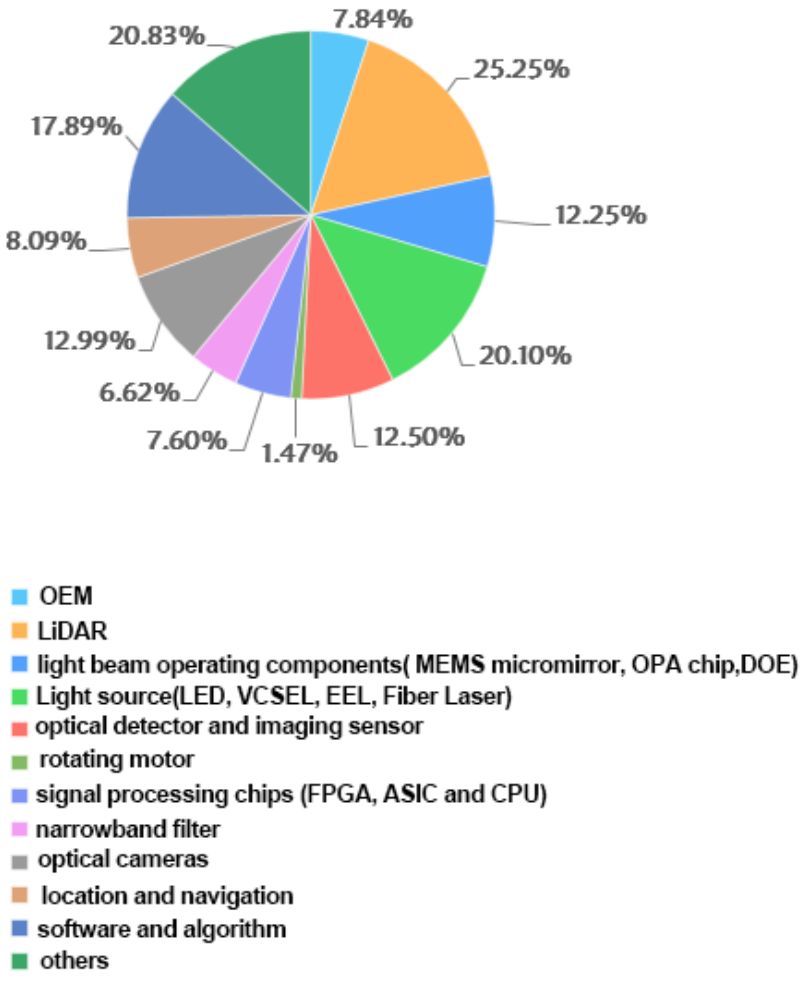


Respondents' distribution by supply chain

此次调查，吸引了激光雷达产业链的上游元器件厂商的积极参与，这充分说明了大家对激光雷达行业持乐观态度，元器件厂商对激光雷达技术的发展保持高度关注。本次调查中，来自光源，例如 LED、垂直腔面发射激光器（VCSEL）、边发射激光器（EEL）、光纤激光器等企业的受调查者为 20.10%，来自光束操纵元件，如 MEMS 微镜、光学相控阵（OPA）芯片、衍射光学元件（DOE）等企业的受调查者为 12.25%；来自光电探测器和图像传感器企业的受调查者为

12.50%；来自光学镜头企业的受调查者为 12.99%；来自位置和导航系统，信号处理芯片如现场可编程门阵列(FPGA)、专用集成电路(ASIC)、中央处理器(CPU)等，窄带滤光片企业的受调查者分别为 8.09%、7.60%和 6.62%。

This survey has attracted the active participation of the manufacturers of components in the upstream of the LiDAR industry chain, which fully indicates that people hold an optimistic attitude towards the LiDAR industry and the manufacturers of components keep a high attention to the development of LiDAR technology. In this survey, 20.10% respondents were from light sources, such as LED, VCSEL, EEL and fiber laser and so on, 12.25% respondents were from light beam operating components, such as MEMS scanning mirror, OPA chip and diffraction optical element (DOE). 12.50% of respondents from photoelectric detector and image sensor enterprises; 12.99% of respondents from optical lens enterprises; The respondents of narrowband filter enterprises were 8.09%, 7.60% and 6.62% respectively from position and navigation systems, signal processing chips such as FPGA, ASIC and CPU.



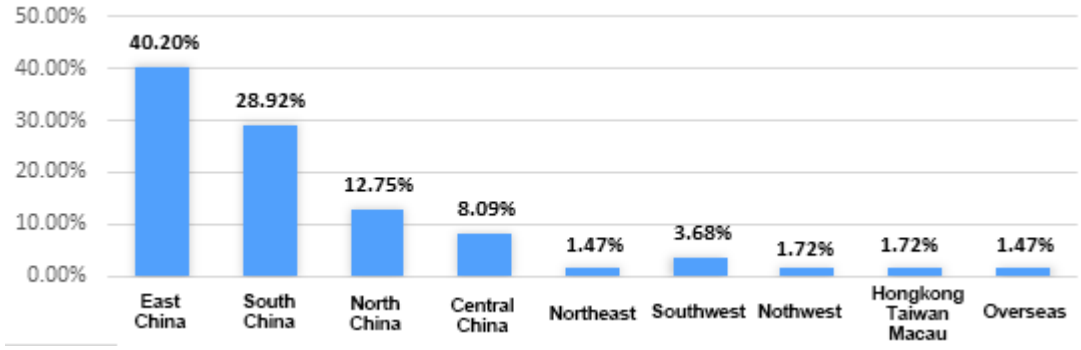
Respondent’s main products

参与调查的企业中，华东地区最为活跃，占 40.20%；其次是华南地区和华北地区，分别为 28.92%和 12.75%。这与中国自动驾驶行业厂商分布有关，北京、广东和江浙沪地区的中国智能驾驶企业最多，同时也是中国经济最为活跃的区域。自动驾驶行业对于知识密度、劳动力水平和工业基础要求较高，上述地区集中了中国绝大多数优质教育资源和高端人力资源，其道路建设和其它基础设施建设也相对完备，是我国最合适发展自动驾驶的区域，自然也是孵化激光雷达企业的最佳地区。Among the enterprises participating in the survey, east China is the most active region, accounting for 40.20%. South China and north China are next with 28.92% and 12.75% respectively. This is related to the distribution of manufacturers in China's autonomous driving industry. Beijing, Guangdong, Jiangsu, Zhejiang and Shanghai regions have the largest number of intelligent driving enterprises in China, and also own China’s most active economies. Self-driving industry is demanding in knowledge density, labor productivity and industrial base, the above regions have gathered China's best high quality education resources and high-end human resources. The construction of roads and other infrastructure construction of these area is also relatively complete, and they are the most appropriate development of autonomous regionals and naturally the best places for hatching LiDAR enterprise.

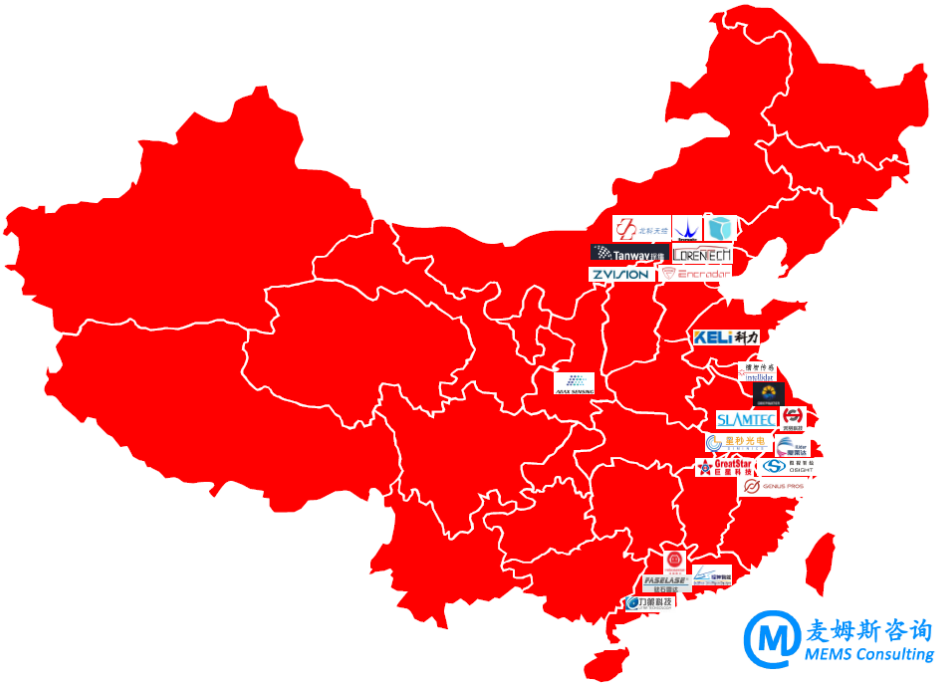
例如，2019 年 3 月北京市印发的《北京市自动驾驶车辆道路测试 2018 年度工作报告》显示，2018 年北京市为 8 家企业的 56 辆自动驾驶车辆发放了道路临时测试牌照，自动驾驶车辆道路测试安全行驶已超过 15.36 万公里；到今年 4 月底，已经分别增长为：9 家企业、60 辆车，及 40.37 公里测试里程；未来一段时间，北京将完善智能网联汽车测试评价体系，同时逐步扩大自动驾驶测试区域和测试道路范围，到 2022 年，北京市智能网联车辆测试区域面积将达到 500 平方公里、开放道路里程达到 2000 公里。在上海，也同样开放了自动驾驶道路。截止 2018 年 9 月，上海市发布了第二阶段智能网联汽车开放测试道路，新的测试道路将在安亭、临港地区规划建设，包括城市主干道、城市次干道、产业园区主干道共十二条道路，共计 31.6km，分别是嘉定区新开放 5.5km 和临港地区新开放的 26.1km，并已向上汽集团、蔚来汽车、宝马汽车等车企发放测试牌照。

For example, according to *the 2018 annual work report of Beijing*

autonomous vehicle road test issued by Beijing in March 2019, Beijing has issued temporary road test licenses for 56 autonomous vehicles for eight enterprises, and the safe driving of autonomous vehicles on the road test exceeded 153,600 kilometers. By the end of April this year, it had grown to 9 enterprises, 60 vehicles and 40.37 kilometers of test mileage respectively. In the future, Beijing will improve the test and evaluation system of intelligent internet-connected vehicles, and gradually expand the range of autonomous driving test areas and test roads. By 2022, the area of intelligent internet-connected vehicles test in Beijing will reach 500 square kilometers and the mileage of open roads will reach 2,000 kilometers. In Shanghai, autonomous roads have also been opened up. By September 2018, Shanghai had issued the second phase of intelligent internet-connected vehicles test road. The new test roads are planning to be constructed in Anting and port-neighboring area, including urban main road, urban secondary road, industrial park main road, a total of 31.6 km, which are Jiading district 5.5 km and 26.1 km of new open port-neighboring area. Shanghai has offered test licenses to SAIC (Shanghai Automotive Industry Corporation), NextEV and BMW.



Respondents by regions

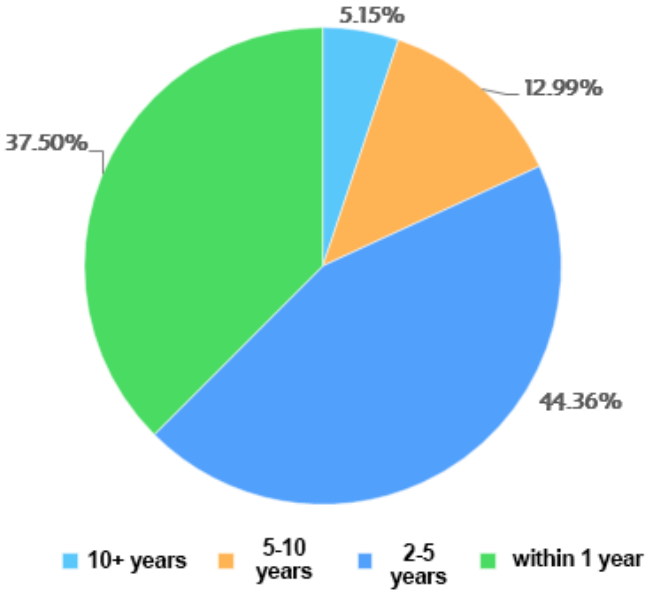


LiDAR Manufacturer Distribution Diagram in China

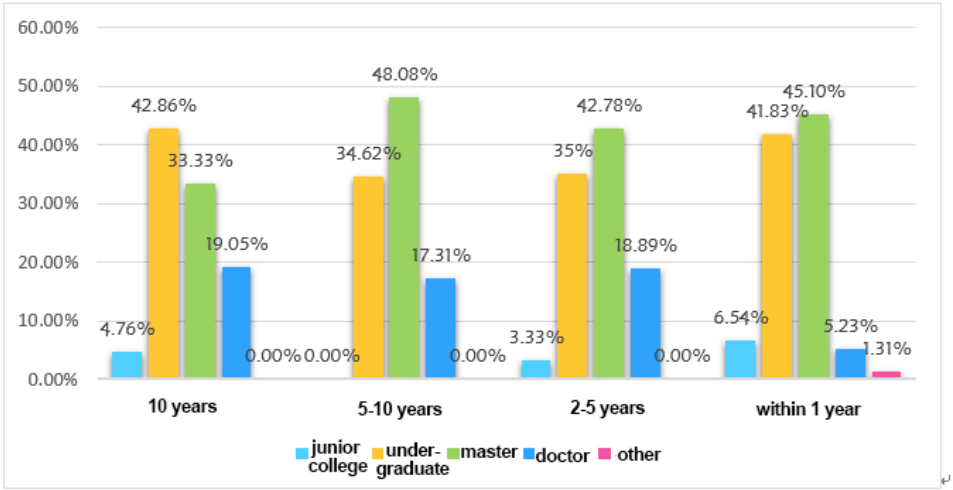
中国激光雷达厂商大多数还处于初创阶段，因此该行业具有丰富经验的从业人员并不多，很多厂商高管为海归人才。就受调查者从事激光雷达行业的经验来看，2~5 年的受调查者占 44.36%；还有较多的受调查者从事激光雷达行业在一年以内，占 37.50%；超过 5 年的受调查者比例仅为 12.99%；10 年以上则寥寥无几。在从事激光雷达行业 10 年以上经验的受调查者中，本科学历居多，占 42.86%，但从事 5~10 年和 2~5 年的受调查者的学历都集中在硕士，分别占 48.08%和 42.78%。

Most Chinese manufacturers are still in their infancy, so there aren't many experienced employees in the industry, and many of their executives are overseas returnees. In terms of the respondents' experience in the LiDAR industry, 44.36% of the respondents have been engaged in the industry for 2 to 5 years. More respondents engaged in the LiDAR industry within one year, accounting for 37.50%; Only 12.99% of respondents have worked in this industry over five years; Few respondents have worked over 5 years. Among the respondents with more than 10 years of experience in the LiDAR industry, the majority has a bachelor's degree, accounting for 42.86%, while those with 5~10 years

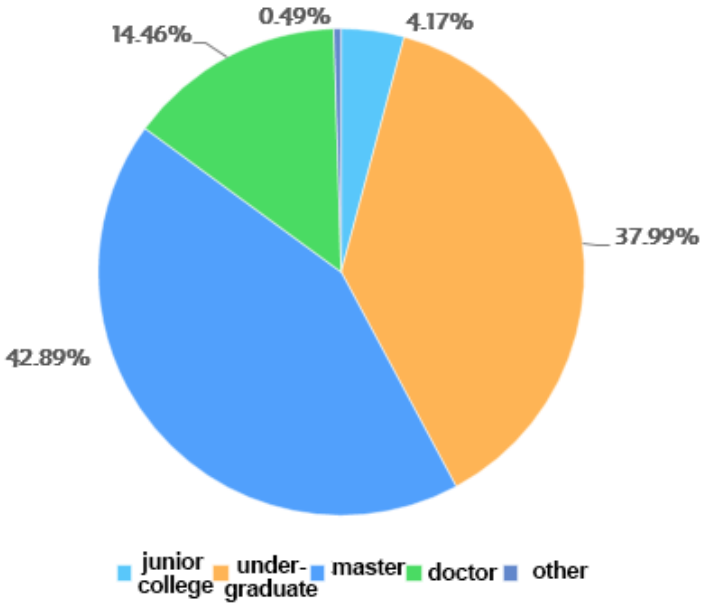
of experience and 2~5 years of experience have a master's degree, accounting for 48.08% and 42.78% respectively.



Respondents' experience in LiDAR Industry



Respondents' education level



Respondents' education level

在对激光雷达及核心元器件技术培训的需求调查中，我们发现受调查者对激光雷达市场信息、技术知识以及核心元器件技术的渴求非常强烈。麦姆斯咨询在“见微知著”培训课程中也策划并组织了相关课程。例如在今年 4 月下旬的《自动驾驶传感技术培训课程》中，就针对激光雷达技术路线，核心元器件如垂直腔面发射激光器（VCSEL）、MEMS 微镜、雪崩光电二极管（APD）、车载镜头等进行技术知识的传授和市场信息的分享，旨在为激光雷达产业培养专业人才贡献力量。麦姆斯咨询即将在 2019 年 7 月 19 日~21 日举办《3D 成像和传感器件培训课程》，本课程邀请 3D 视觉产业链优秀讲师，以核心元器件为出发点，解析 3D 成像与传感技术：（1）红外光源技术，深度剖析 VCSEL；（2）MEMS 光束操纵技术，覆盖多种 MEMS 微镜原理（静电式、电磁式、电热式、压电式）；（3）液体透镜；（4）衍射光学元件（DOE）；（5）高性能光电探测：SPAD/SiPM；（6）光电探测面阵：ToF 图像传感器；（7）光学 MEMS 和传感器仿真技术。

In the survey of the demand for LiDAR and core component technology training, we found that respondents have a very strong desire for LiDAR market information, technical knowledge and core component technology. MEMS Consulting also plans and organizes courses in its "knowing by sight" training program. For example in late April of this year's 《autonomous sensing technology training course》, MEMS

Company focus on the LiDAR technology route, the core components such as vertical cavity surface emitting laser (VCSEL), MEMS scanning mirror, avalanche photodiode (APD), vehicle camera and other technical knowledge to teach and share market information, to contribute its strength in cultivating professional talents of LiDAR industry. MEMS Consulting will hold《the training course of 3D imaging and sensor components》from July 19 to 21, 2019. This course will invite excellent instructors of 3D visual industry chain to analyze 3D imaging and sensing technology based on core components : (1) infrared light source technology, in-depth analysis of VCSEL; (2) MEMS beam manipulation technology, covering a variety of MEMS scanning mirror principles (electrostatic, electromagnetic, electro-thermal and piezoelectric); (3) liquid lens; (4) diffraction optical element (DOE); (5) high-performance photoelectric detection: SPAD/SiPM; (6) photoelectric detection array: ToF image sensor; (7) optical MEMS and sensor simulation technology.

第二部分：激光雷达行业市场趋势分析 Market trend analysis of LiDAR industry

2.1 汽车 ADAS 和自动驾驶是激光雷达主要应用 Automotive ADAS and autonomous driving are the main applications of LiDAR

作为雷达和激光共同“孕育”的产物——激光雷达起源于 20 世纪 60 年代早期，首次应用是在气象学中，国家大气研究中心用它来测量云层。但走入公众视野，则是在 1971 年阿波罗执行 15 号任务期间宇航员采用一种激光雷达设备——激光高度计来绘制月球表面图。由此，激光雷达的精准度和用处得到了证明。

激光雷达技术从最简单的激光测距技术开始，逐步发展出激光跟踪、激光扫描成像、激光多普勒成像等技术，同时，激光雷达应用领域也逐渐拓展。此前的几十年，激光雷达在军事领域广受欢迎，作为一种能够抵抗电子战、反辐射导弹、超低空突防和隐身的高灵敏雷达，可以探测和跟踪目标，获得目标方位、速度等信息，即使身价不菲，但仍不能阻挡不了各国军事部门矢志不渝地对其精益求精的追求。

As a joint product of radar and laser, LiDAR originated in the early 1960s and was first used in meteorology, and the NCAR (national center for atmospheric research) used it to measure clouds. But it came to public view in 1971, during the Apollo 15 mission, when astronauts used a LiDAR device called a laser altimeter to map the surface of the moon. Thus, the accuracy and usefulness of LiDAR have been proved.

LiDAR technology starts from the simplest laser ranging technology, and gradually develops laser tracking, laser scanning imaging, laser doppler imaging and other technologies. At the same time, the application field of LiDAR is also gradually expanded. In the previous decades, LiRAD is popular in military field, as a kind of resistant to electronic warfare, anti-radiation missile, a low-level penetration and stealth high sensitivity radar, can detect and track the target, the target position, speed and other information. Though expensive, it still can not

stop the national military commitment to the pursuit of LiRAD' s excellence.

激光雷达用于汽车的故事始于一项比赛。自 2004 年起，美国国防部高级研究计划局（DARPA）开始组织一项大型无人车挑战赛，旨在鼓励开发自动驾驶汽车，激光雷达及传感器融合技术成为赢得挑战赛的利器。

汽车制造商可能认为在高度自动驾驶时才会使用激光雷达，而在 SAE（美国汽车工程师学会） L3 级以下应用只需采用摄像头和毫米波雷达的组合。因此，激光雷达将主要被高端的高级驾驶辅助系统（ADAS）和自动驾驶汽车采用，并且自动驾驶汽车被视为改变激光雷达产业的重要力量。

The story of LiDAR for cars began with a match. Since 2004, America defense advanced research projects agency (DARPA) has been running a big autonomous vehicle challenge, which aims to encourage the development of autonomous cars， LiDAR and sensor fusion technology became the winning tools.

While automakers may think of using LiDAR during a highly autonomous ride, applications below SAE (American society of automotive engineers) L3 require only a combination of camera and millimeter-wave radar. As a result, LiDAR will be used primarily by high-end advanced driving assistance systems (ADAS) and autonomous vehicles, and autonomous vehicles are seen as an important force in transforming the LiDAR industry.

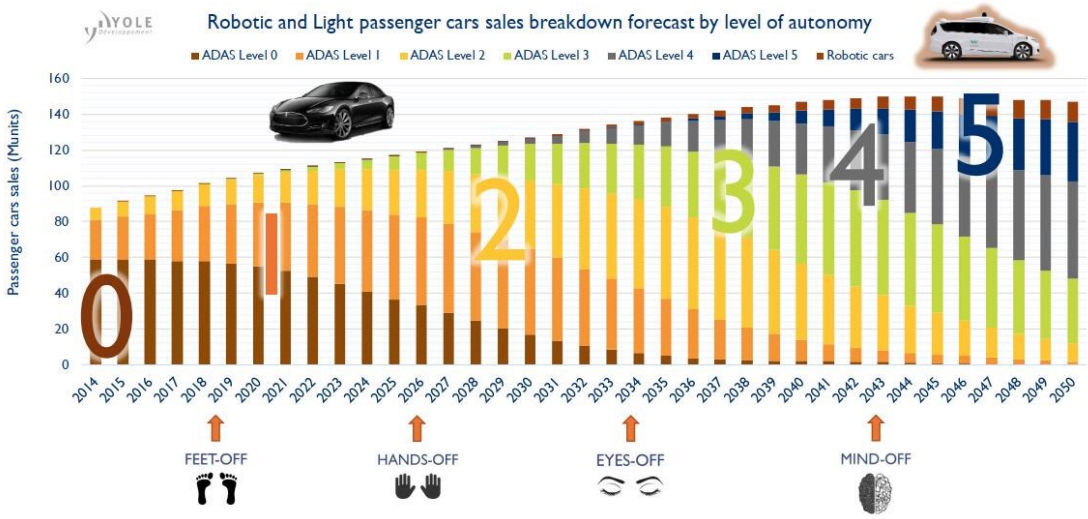


图 10：不同 SAE 等级汽车及自动驾驶汽车的市场渗透率情况

（来源：《汽车和工业应用的激光雷达-2019 版》）

在本次调查中，80.64%的受调查者认为激光雷达的最主要应用领域是在汽车 ADAS 和自动驾驶。不过，激光雷达的新兴应用领域不局限于汽车。该技术越来越多地用于建筑和地理信息系统，也是自动导向车（AGV）的关键组成部分，可以帮助仓库实现自动化。因此，58.09%的受调查者认为地形测绘也是激光雷达主要的应用领域，50.25%的受调查者依然看好激光雷达在国防军事领域的应用前景，而 50.74%的受调查者认为 AGV 小车是激光雷达的主要应用领域。

In this survey, 80.64% of the respondents believe that the most important application fields of LiDAR are car ADAS and autonomous driving. But LiDAR's emerging applications are not limited to cars. The technology, which is increasingly used in architectural and geographic information systems, is a key component of automated guided vehicles (AGV) that help automate warehouses. Therefore, 58.09% of the respondents believe that topographic mapping is also the main application field of LiDAR, 50.25% of the respondents are still optimistic about the application prospect of LiDAR in the field of national defense and military, and 50.74% of the respondents believe that AGV car is the main application field of LiDAR.

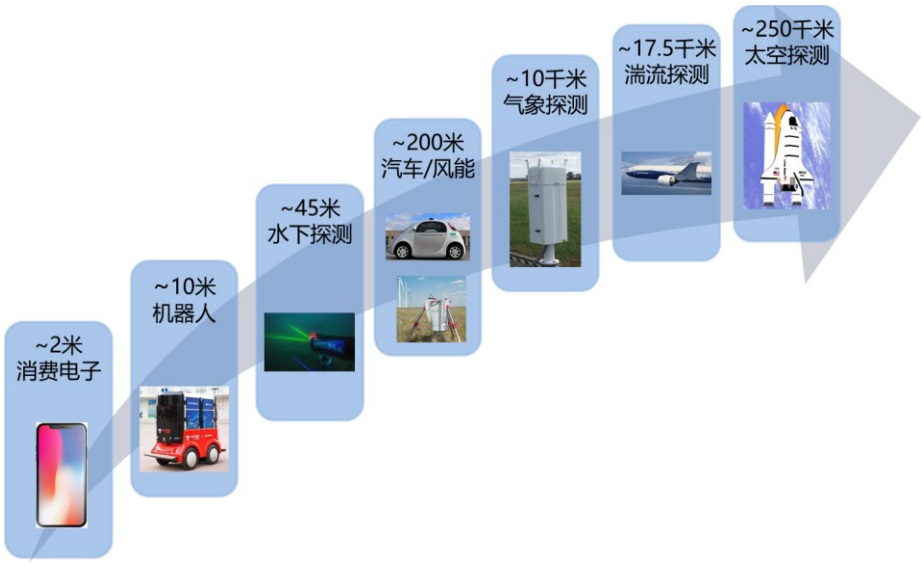
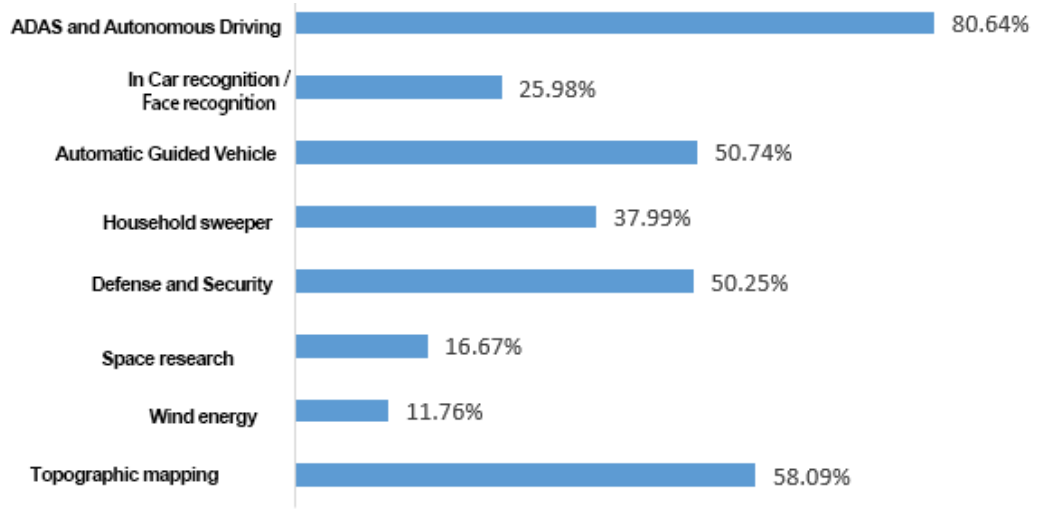


图 11：激光雷达应用领域及测距范围



Respondents 'opinion on LiDAR applications

2.2 自动驾驶市场将成为激光雷达产业爆发点共识已形成 A consensus that autonomous driving market will become LiDAR industry breakout point

激光雷达的应用正在按计划实施，其它汽车制造商已宣布或计划将激光雷达技术整合到未来的汽车之中。据麦姆斯咨询报道，宝马（BMW）与 Innoviz 展开合作，计划在 2021 年将基于 MEMS 微镜的激光雷达集成于汽车，表明固态技术将逐渐取代机械扫描技术。在互联网企业方面，Waymo 并不孤单，因为百度（Baidu）、优步（Uber）、Lyft 等也加入了自动驾驶战局。

LiDAR applications are on track, and other automakers have announced or planned to integrate LiDAR technology into future vehicles. BMW has cooperated with Innoviz to integrate a LiDAR based on MEMS scanning mirrors into cars by 2021, indicating that solid-state technology will gradually replace mechanical scanning. As for Internet enterprises, Waymo is not alone since companies like Baidu, Uber, Lyft and others have also entered the self-driving war.

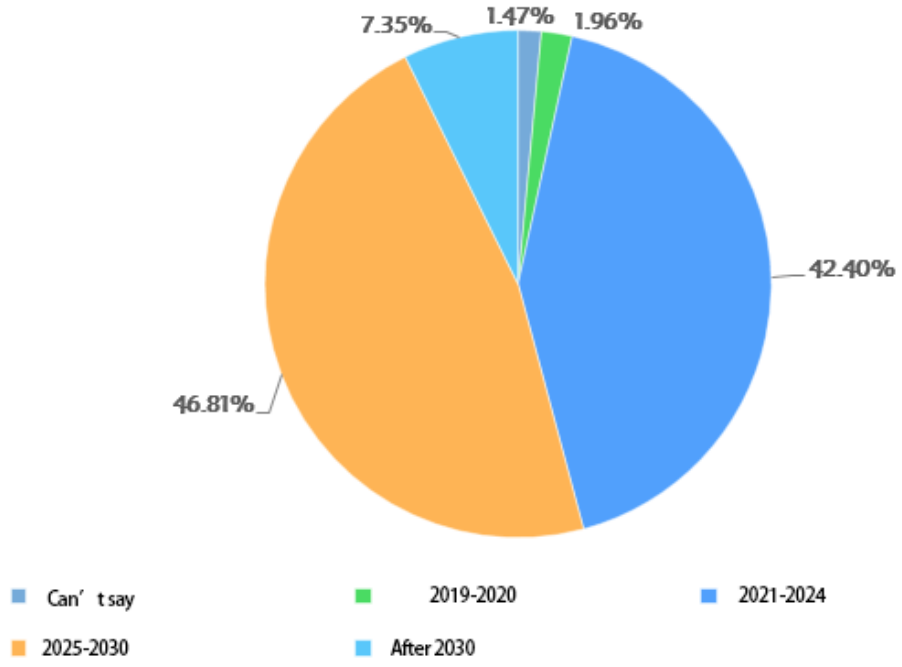
随着上述企业的快速发展，预计到 2021 年，自动驾驶汽车的总量将达到 44000 辆。与此同时，激光雷达市场也因此受益，Yole 在《汽车和工业应用的激光雷达-2019 版》中预计激光雷达市场将从 2018 年的 13 亿美元增长到 2024 年的 60 亿美元。其中，汽车应用占据激光雷达市场的 70%份额。

With the rapid development of these enterprises, the total number

of autonomous vehicles is expected to reach 44,000 by 2021. At the same time, the LiDAR market is also benefiting. Yole predicts in 《LiDAR for automotive and industrial applications 2019》 that the LiDAR market will grow from $1.3 billion in 2018 to $6 billion in 2024.Of these, automotive applications account for 70% of the LiDAR market.

在本次调查中，智能驾驶市场会成为激光雷达产业的爆发点也获得高度一致的共识，93.38%的受调查者同意此观点。而关于具体爆发时间点的调查中，大多数受调查者认为激光雷达市场爆发将出现在 2021~2030 年之间，其中认为 2025~2030 年爆发的受调查者比例更高。

In this survey, there is a high consensus that smart driving market will become the flashpoint of LiDAR industry, with 93.38% of respondents agreeing with this view. In the survey of specific time of outbreak points, the major respondents believe that the outbreak of LiDAR market will occur between 2021 and 2030, among which a higher proportion of respondents believes that the outbreak will occur between 2025 and 2030.



Respondents ‘ prediction on LiDAR blooming time

2.3 激光雷达行业投资状况分析 Investment status analysis of LiDAR industry

智能驾驶概念引入以来，激光雷达领域的投资热潮热度不减，一些成立不久的初创企业动辄就获得上千万的融资额度。据麦姆斯咨询介绍，从 2016 年以来，激光雷达行业的投资已经超过了 10 亿美元。

Since the introduction of the concept of intelligent driving, the investment boom in the field of LiDAR continues unabated. Some newly-established start-ups often get tens of millions of financing. Since 2016, investments in the LiDAR industry have exceeded $1 billion, according to MEMS Company.

在这样的背景下，一些对激光雷达行业投资泡沫过大的抨击不绝于耳。但本次调查中，54.66%的受调查者认为激光雷达行业的投资情况属于正常水平，也有近三成的受调查者认为存在投资过热的现象。

In this context, critics attacking the LiDAR industry investment bubble are on the rise. However, in this survey, 54.66% of the respondents believe that the investment situation of LiDAR industry is normal, and nearly 30% respondents believe that there exists overheating investment.

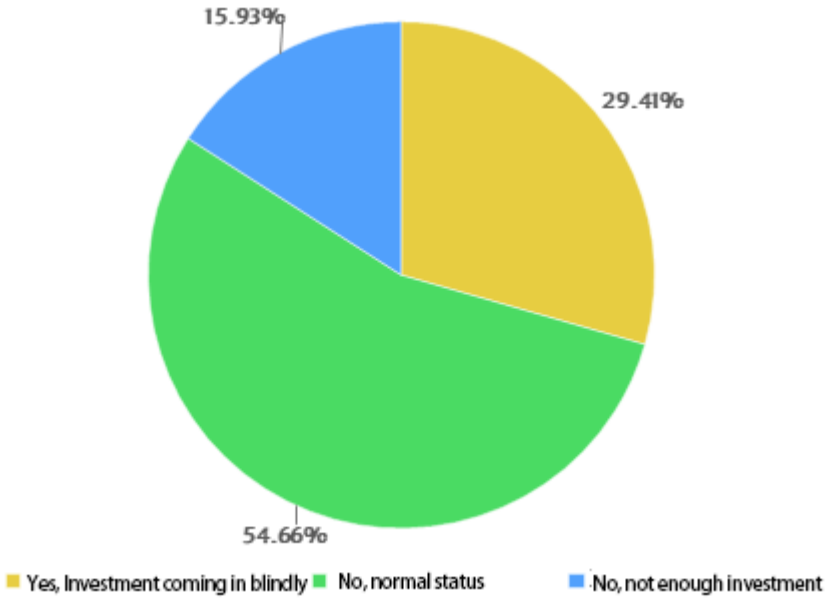
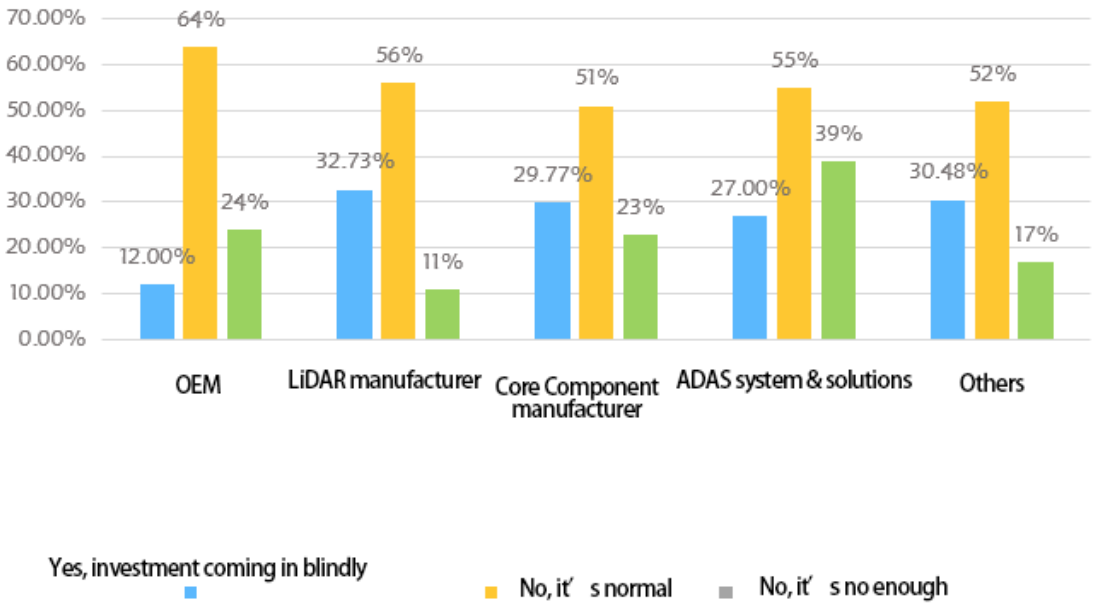


图 14：受调查者对激光雷达行业投资热度看法分析

Respondents ' opinion on investment of LiDAR industry

其中自动驾驶系统集成及解决方案商、整车厂分别有 39%和 24%的受调查者认为激光雷达行业存在投资力度不够的情况。可推测自动驾驶的激光雷达产品还未解决整车厂、自动驾驶系统集成及解决方案商的痛点，需要更多资金去支持激光雷达行业产品的技术研发。

Among them, 39% and 24% of respondents believe that the investment in LiDAR industry is not enough. It can be inferred that autonomous driving LiDAR products have not yet solved the pain points of vehicle manufacturers, autonomous driving system integration and solution providers, and more funds are needed to support the technical research and development of LiDAR products.



Different types companies' opinion on investment of LiDAR industry

2.4 亚太地区激光雷达市场被一致看好 The Asia - Pacific LiDAR market is generally optimistic

68.87%的受调查者认为未来激光雷达市场主要集中于亚太地区，而只有8.09%的受调查者认为未来激光雷达市场主要集中于欧洲地区。但需要考虑该数据与受调查者集中于中国，及中国拥有全球第一的汽车销量有关。

68.87% of respondents believe that the future LiDAR market will mainly focus on the Asia-pacific region, while only 8.09% believe that the future LiDAR market will mainly focus on the European region. But you need to consider the data related to the concentration of respondents in China and the fact that China has the world's largest auto sales.

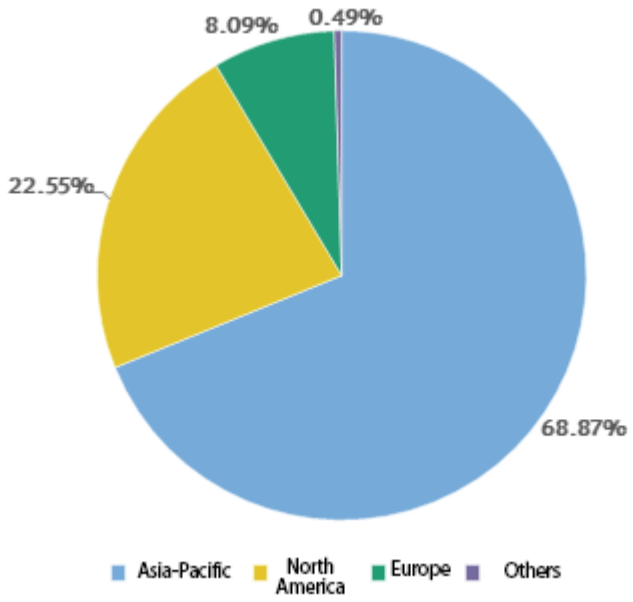


图 16：受调查者对未来激光雷达集中地区的看法

Respondents ‘ opinion on future LiDAR regions

不过，有数据显示欧洲才将会占据全球汽车激光雷达传感器最大的市场份额。欧盟正在支持基于激光雷达的 ADAS 应用合法化，以提高车辆的安全性。自动驾驶汽车已经在该地区的几个国家进行测试，如德国和法国等。这将增加欧洲地区对基于激光雷达传感器的 ADAS 系统的应用，并将最终影响该地区在全球所占的市场份额。

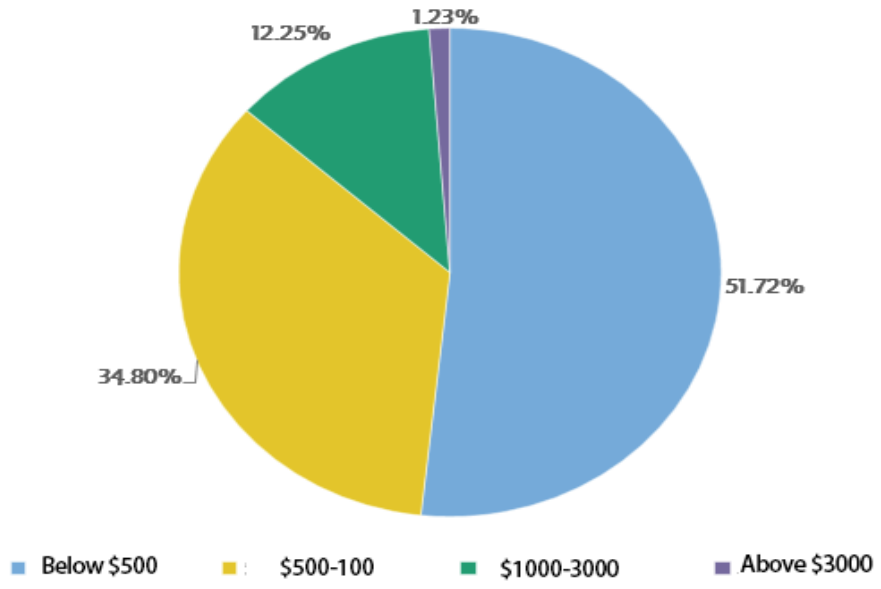
However, figures suggest that Europe will take the largest share of the global market of LiDAR sensors for cars. The European Union is supporting legalization of ADAS applications based on LiDAR to improve vehicle safety. Self-driving cars have been tested in several countries in the region, such as Germany and France. This will increase the use of ADAS systems based on LiDAR sensor in Europe and will ultimately affect the region's global market share.

2.5 降低激光雷达价格是一致呼声 Lowering the price of LiDAR is a unanimous call

激光雷达的“高冷”来源于其昂贵的销售价格，机械式激光雷达常常高于一辆普

通汽车的售价，因此广为业界所诟病。满足性能要求的同时，实现大规模量产，并降低成本，是汽车激光雷达厂商的目标。在本次调查中，51.72%的受调查者认为激光雷达的价格应在 500 美元以下才比较合理，34.80%的受调查者认为 500~1000 美元才算合理。

The "high cold" of LiDAR is due to its high selling price. The mechanical LiDAR is often higher than the price of an ordinary car, so it is widely criticized by the industry. It is the target of automobile LiDAR manufacturer to achieve mass production and reduce cost while meeting the performance requirement. In this survey, 51.72% of the respondents think that the price of LiDAR should be less than $500, and 34.80% of the respondents think that only $500~ $1000 is reasonable.



Price of LiDAR

我们对来自受调查者所处的激光雷达产业链位置进行了细分。发现整车厂 72%的受调查者和自动驾驶系统及解决方案商 65%的受调查者认为激光雷达需要降至 500 美元以下，说明目前整车厂、自动驾驶系统及解决方案商认为激光雷达售价高，需要降低激光雷达产品价格从而降低智能驾驶系统的整体成本。但在激光雷达厂商的受调查者中，认为价格在 500 美元以下和 500~1000 美元的人分别都占有 45.45%和 40.00%，可以看出激光雷达还有较多的技术难点，核

心元器件成本较高，导致激光雷达厂商和核心元器件厂商更理性地判断为价格区间为 500~1000 美元。

We have subdivided the LiDAR industrial chain position of the respondents and found 72% of OEMS respondents, and 65% of automatic driving system and solution provider think the price of LiDAR need to fall below $500, indicating the current OEMS, autopilot system and solution providers think the price is high, the price of LiDAR products needs to be lowered to reduce the overall cost of intelligent driving system. However, among the respondents of LiDAR manufacturers, those who believe that the price is below $500 and between $500 and $1,000 account for 45.45% and 40.00% respectively. It is indicated that LiDAR still has many technical difficulties. The high cost of core components leads to the more rational judgment of LiDAR and core component manufacturers that the price range is between $500 and $1,000.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智能驾驶领域的应用及发展

第三部分：激光雷达技术方案分析 Analyze of LiDAR Technology Scheme

3.1 激光雷达 LiDAR

3.1.1 展望中长期，更看好 MEMS 激光雷达 Long - term prospects, more optimistic about the MEMS LiDAR

通常情况下，“采用半导体‘微动’器件——MEMS 微镜（代替宏观机械式扫描器）在微观尺度上实现激光雷达发射端的光束操纵方式”称为“混合固态”。同时，把采用上述光束操纵方式的激光探测和测距系统称为混合固态激光雷达，也称为 MEMS 激光雷达。“混合固态”的概念源于 MEMS 微镜是一种硅基半导体元器件，属于固态电子元件；但是 MEMS 微镜并不“安分”，内部集成了“可动”的微型镜面； 由此可见 MEMS 微镜兼具“固态”和“运动”两种属性，故称为“混合固态”。可以说，MEMS 微镜是传统机械式激光雷达的革新者，引领激光雷达的小型化和低成本化。

In general, "using semiconductor 'micro motion' device - MEMS scanning mirror (instead of macroscopic mechanical scanner) to achieve LiDAR transmitter beam control mode at the micro scale" is called "hybrid solid state". At the same time, the laser detection and ranging system using the above beam control mode is called hybrid solid-state LiDAR, also known as MEMS LiDAR. The concept of "mixed solid state" originates from MEMS scanning mirror, which is a semiconductor based on silicon component and a solid state electronic component. But MEMS scanning mirror is not "peaceful", the internal integration of "movable" scanning mirror; It can be seen that MEMS scanning mirror has two characteristics of "solid state" and "motion", so it is called "mixed solid state". It can be said that MEMS scanning mirror is the innovator of traditional mechanical LiDAR, leading the trend of LiDAR miniaturization and low-cost.

而光学相控阵（OPA，Optical Phased Array）激光雷达，其相控阵发射器由若干发射接收单元组成阵列，通过改变加载在不同单元的电压，进而改变不同单元发射光波特性（如光强、相位），实现对每个单元光波的独立控制. 通过调节从每个相控单元辐射出的光波之间的相位关系，在设定方向上产生互相加强的干涉从而实现高强度光束，而其它方向上从各个单元射出的光波彼此相消，因此，辐射强度接近于零。

组成相控阵的各相控单元在程序的控制下，可使一束或多束高强度光束的指向按设计的程序实现随机空域扫描。OPA 激光雷达动态扫描性能最佳、集成度高、信噪比高等优点。但是，如果要实现完美 OPA 阵列，需要天线密度高、阵列规模大的天线阵列，同时会带来硅波导串扰、加工难度高、成本高等一系列问题。

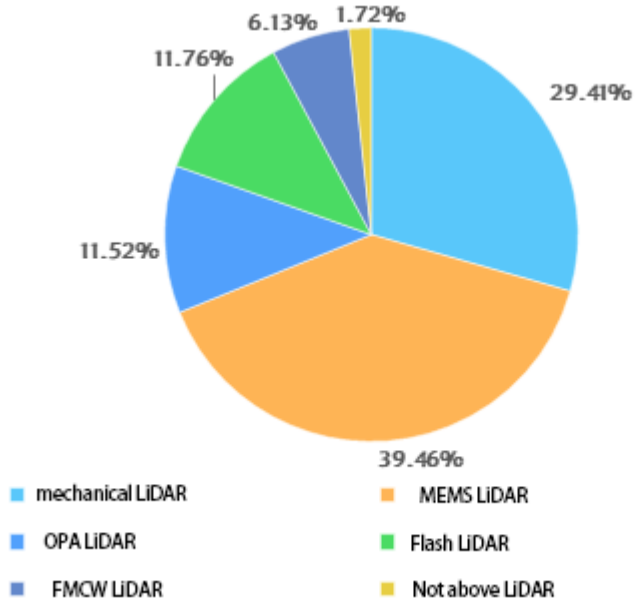
And Optical Phased Array (OPA) LiDAR, the Phased Array transmitter is composed of several emission receiver unit Array, by changing the load voltage in different units to change the different unit emission light features such as light intensity, phase, and realize the independent control of each unit light waves. By regulating the phase relationship from each phase unit between the light emission, reinforcing each other in setting direction so as to realize the interference of high intensity beams, and waves of light from the units in other directions cancel each other out, therefore, the radiation intensity is close to zero.

Under the control of the program consisting different phased-array elements, each phase control unit of the phased array can make the direction of one or more high-intensity beams to realize random spatial domain scanning according to the designed program. OPA LiDAR has the advantages of best dynamic scanning performance, high integration and high signal-to-noise ratio. However, to realize the perfect OPA array, the antenna array with high antenna density and large array size are required, which may bring a series of problems such as silicon waveguide crosstalk, high processing difficulty and high cost.

一直以来，业界将 MEMS 激光雷达视为最快落地的技术路线。在本次调查中，也得到了相同的共识！在“法雷奥的 4 线机械式激光雷达 SCALA 是目前唯一通过车规的激光雷达产品，您认为下一款最有可能的通过车规的激光雷达？”这个问题的调查中，39.46%的受调查者选择了 MEMS 激光雷达，也有 29.41%

的受调查者坚持选择机械式激光雷达。而闪光（Flash）激光雷达和 OPA 激光雷达分别位列第三位和第四位。(注：有关法雷奥的 4 线机械式激光雷达 SCALA 的详细报告请参考《法雷奥 SCALA 激光扫描仪》。)

For a long time, MEMS LiDAR are regarded as the fastest landing technology route. In this survey, people also got the same consensus! "Valeo's 4-line mechanical LiDAR SCALA is currently the only LiDAR product that passes the regulation, which type of LiDAR do you think is most likely to pass the regulation?" In the survey of this question, 39.46% of respondents chose MEMS LiDAR, while 29.41% insisted on mechanical LiDAR. Flash LiDAR and OPA LiDAR ranked third and fourth respectively.(note: for a detailed report on Valeo's 4-line mechanical LiDAR SCALA, please refer to *Valeo SCALA laser scanner*)

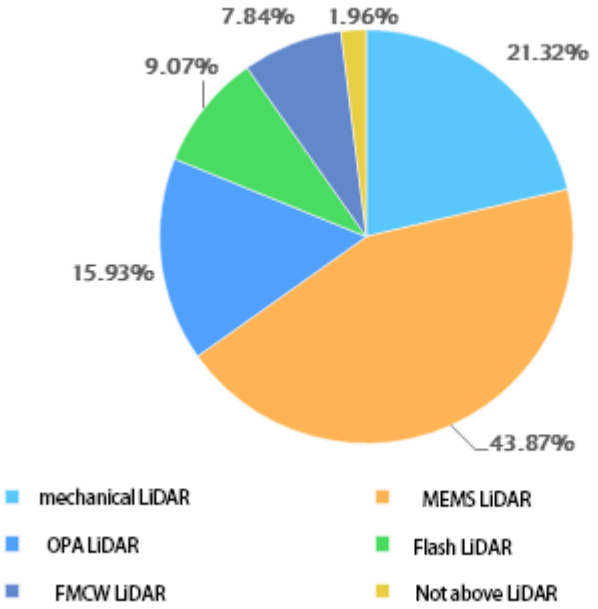


Respondents Opinion on the 2nd LiDAR able to pass pass the vehicle regulation

在未来 5~10 年所看好的激光雷达技术路线的调查中，我们看到超过四成的受调查者选择了 MEMS 激光雷达，MEMS 激光雷达依然是最有潜力的种子选手！我们也看到，有 21.32%的受调查者坚持选择机械式激光雷达。这也充分说明了，虽然机械式激光雷达存在体积大、装配难度大、可靠性不够高等各种问题，但机械式激光雷达的成熟度高仍是其它激光雷达技术路线暂时无法企及的。在其它激光雷达技术路线尚未证明自己的真正实力前，仍然有不少人士继续看好机械式激光雷达，超过六成的受调查者认为机械式激光雷达还将存在 5 年以上。

In the survey of LiDAR technology route in the next 5~10 years, we

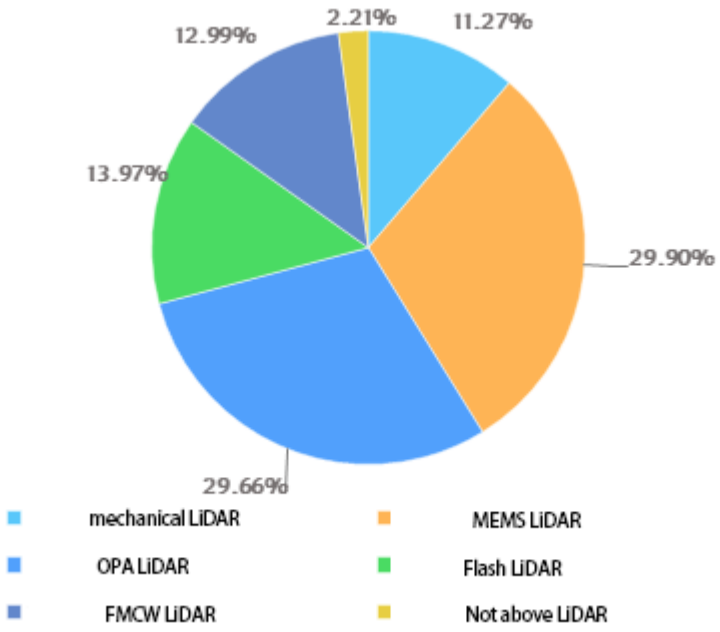
see that more than 40% of respondents choose MEMS LiDAR, and MEMS LiDAR is still the most potential seed player! We also found that 21.32% of the respondents insisted on mechanical LiDAR. This also fully explains that although mechanical LiDAR has various problems such as large volume, difficult assembly and insufficient reliability, the high maturity of mechanical LiDAR is still temporarily unattainable by other LiDAR technology routes. While other LiDAR technologies have not proved their real strength, many people continue to be optimistic about mechanical LiDAR, with more than 60% of the respondents believing that mechanical LiDAR will still exist for more than five years.



Respondents Opinion on Types of LiDAR in 5-10 years

而谈及未来 10~20 年看好的激光雷达技术路线，MEMS 激光雷达和机械式激光雷达的比例均有下降，分别下降至 29.90%和 11.27%。而 OPA 激光雷达和 Flash 激光雷达作为全固态激光雷达的代表，将有望在激光雷达舞台上崛起，有 29.66%和 13.97%的受调查者分别选择了 OPA 激光雷达和 Flash 激光雷达。

As for the promising LiDAR technology route in the next 10 to 20 years, the proportion of MEMS LiDAR and mechanical LiDAR has decreased to 29.90% and 11.27% respectively. As representatives of all-solid-state LiDAR, OPA LiDAR and Flash LiDAR are expected to rise on the LiDAR stage, with 29.66% and 13.97% of respondents choosing OPA LiDAR and Flash LiDAR respectively.



Respondents Opinion on Types of LiDAR in 10-20 years

3.1.2 多因素阻碍激光雷达通过车规 Many factors prevent the LiDAR from passing through the car gauge

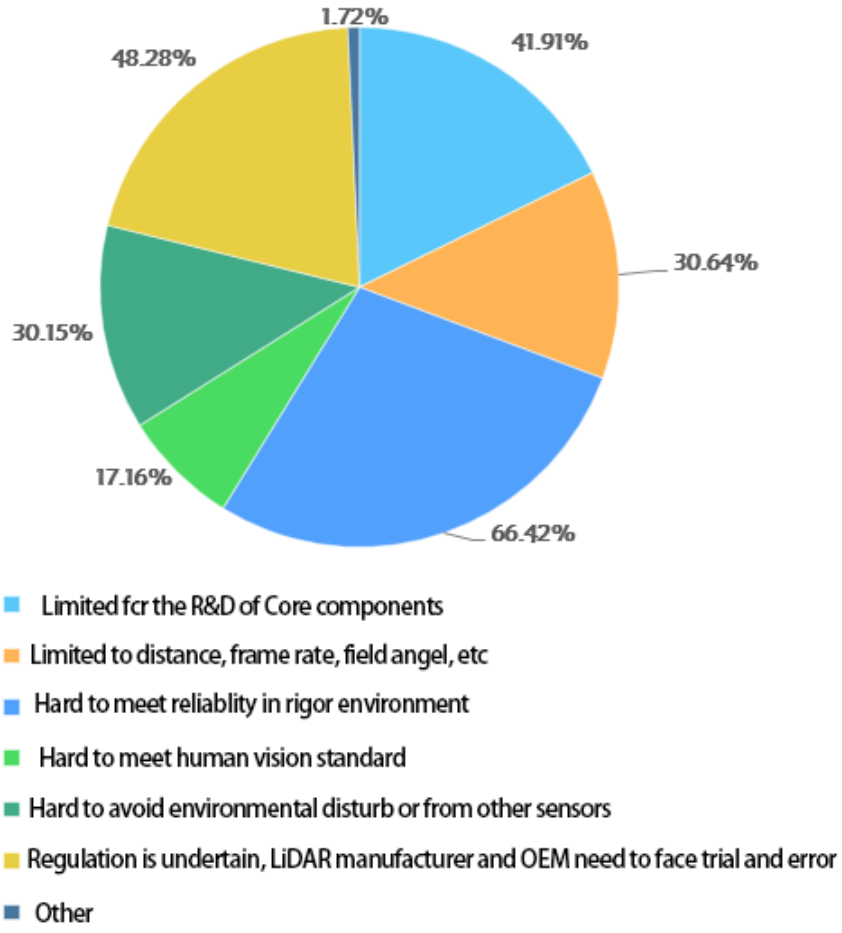
激光雷达用于自动驾驶汽车面临的最大问题有测量距离、人眼安全和车规等。其中，作为一门在汽车应用领域的新兴技术，激光雷达对应的车规标准该如何定义？怎样才能通过车规？这些都是激光雷达厂商所面临的问题。

66.42%的受调查者认为激光雷达通过车规的主要问题是难以满足严苛车用环境的可靠性要求；还有 48.28%的受调查者认为是车规标准不明确，激光雷达厂商和整车厂都需要经过试错阶段才能通过车规；41.91%的受调查者认为核心元器件的研制进展缓慢影响了激光雷达通过车规的进程。

The biggest problem faced by LiDAR in autonomous vehicles include measuring distance, human eye safety and car gauge. Among them, as an emerging technology in the field of automotive application, how to define the car regulation standard corresponding to LiDAR? How can I get through the rules? These are the problems faced by LiDAR manufacturers.

66.42% respondents believe that the main problem of LiDAR passing vehicle regulations is that it is difficult to meet the reliability requirements of the harsh vehicle environment. 48.28% of the respondents believed

that the standard of car regulations was not clear, and both LiDAR manufacturers and OEMS needed to go through the trial and error stage to pass the regulation.41.91% of respondents believed that the slow development of core components affected the progress of LiDAR passing through vehicle regulations.



Respondents Opinion on the situation for LiDAR to pass regulations

3.1.3 对中国激光雷达技术科研水平持积极乐观态度 We are optimistic about the scientific research level of LiRAD technology in China

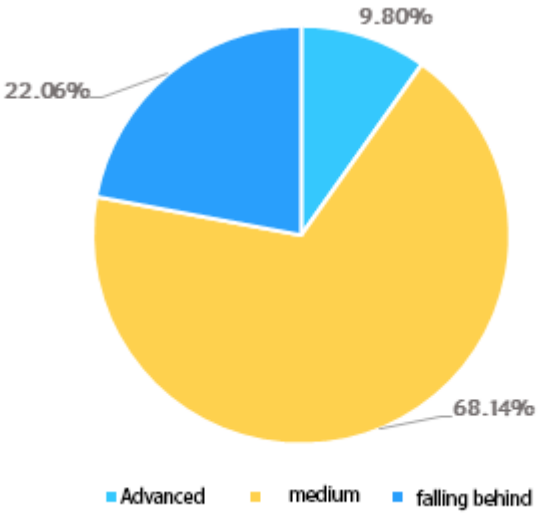
目前，中国已经涌现出几十家激光雷达初创企业，第一梯队以禾赛科技、速

腾聚创、镭神智能、北科天绘等为代表，这些企业近几年发展迅速，在国内外激光雷达市场上已经树立了良好的品牌形象。而国外企业如 Velodyne、Sick、Hokuyo、Valeo/Ibeo 已经抢先占领了激光雷达市场。中国作为世界第一大汽车产销国，连续十年蝉联全球第一。汽车电子智能化的快速发展，正在快速地重构整个产业，让汽车与外界互联互通，汽车本身正在朝着高度协同化、集成化和智能化的方向飞速发展。汽车自动驾驶主要通过激光雷达、摄像头（CMOS 图像传感器模组）、毫米波雷达和超声波传感器实现 3D 视觉及测距功能。中国在全球汽车市场的地位为中国发展自动驾驶，发展激光雷达技术及应用提供了丰沃的土壤。At present, China has emerged dozens of LiDAR start-up enterprises, the first echelon representatives including HESAI, RoboSense, LeiShen Intelligent System, Surestar and so on, these enterprises have developed rapidly and has set up a good brand image in recent years at home and abroad. Foreign firms, such as Velodyne, Sick, Hokuyo and Valeo/Ibeo, have already occupied the LiDAR market. China, as the world's largest automobile manufacturer and owns the biggest market, has been ranked number one in the world for ten consecutive years. The rapid development of intelligent automobile electronics is rapidly reconstructing the whole industry to connect the automobile and the outside world. The automobile itself is developing rapidly towards the direction of highly coordinated, integrated and intelligent. Auto autonomous driving mainly realizes 3D vision and ranging functions through LiDAR, camera (CMOS image sensor module), millimeter wave radar and ultrasonic sensor. China's position in the global automotive market provides fertile ground for China to develop autonomous driving, LiDAR technology and applications.

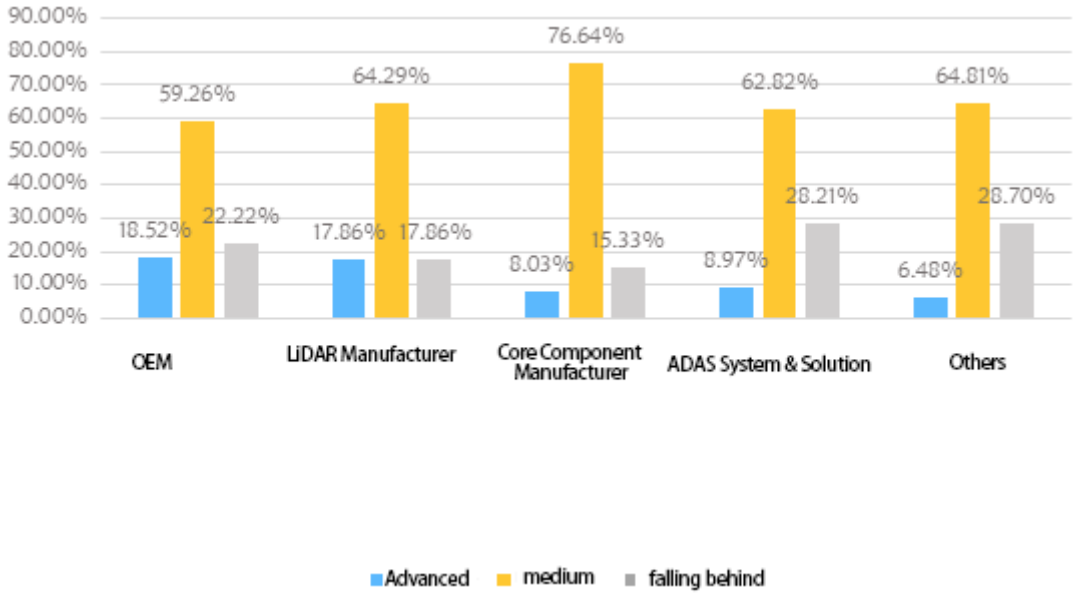
对“目前中国的激光雷达技术在全球所处水平”的调查中，68.14%的受调查者认为目前中国激光雷达技术在全球处于中等水平，仅仅只有 9.80%的受调查者认为中国激光雷达技术属于领先水平。可见，中国激光雷达技术和国际领先激光雷达技术仍有较大差距，还有一定的进步空间。

In the survey of "the current level of China's LiDAR technology in the world", 68.14% of respondents think that China's LiDAR technology is at the medium level in the world, and only 9.80% of respondents think that

China's LiDAR technology is at the leading level. It can be seen that there is still a big gap between China's LiDAR technology and international leading LiDAR technology, and there is still some room for progress.



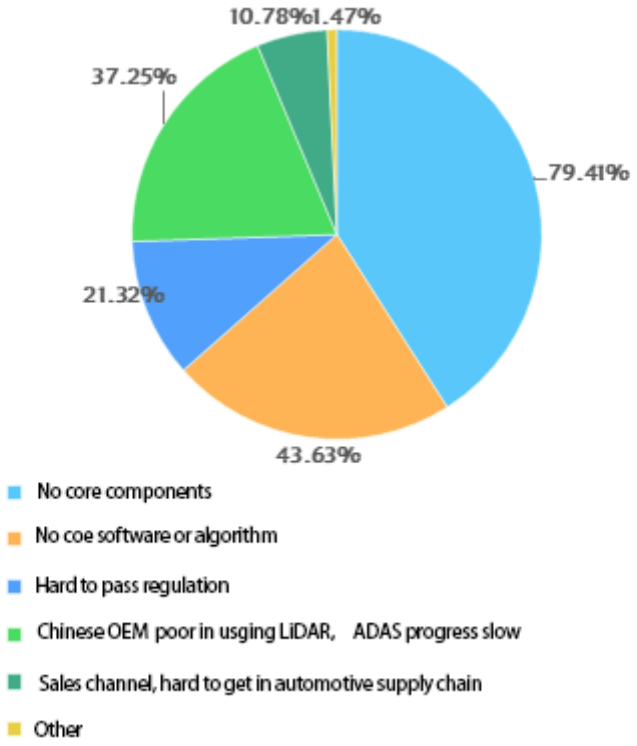
Respondents Opinion on Chinese LiDAR level



Different companies' Opinion on Chinese LiDAR levl

中国在发展激光雷达产业过程中，“没有掌握核心元器件”被普遍认为会成为“卡脖子”环节。据麦姆斯咨询介绍，激光雷达核心元器件主要掌握在欧美日

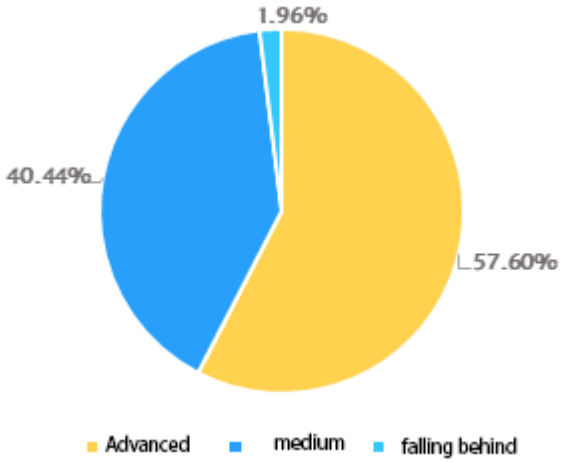
手中，在当前中美贸易战背景下，打造强健有力的“中国芯”的重要性不言而喻。
In the process of developing LiDAR industry in China, "not mastering the core components" is generally considered to be a "neck jam" link. According to MEMS Company, the core components of LiDAR are mainly in the hands of Europe, the United States and Japan. In the context of the current trade war between China and the United States, the importance of building a robust "China core" is self-evident.



Bottleneck of LiDAR industry in China

不过，57.60%的受调查者对于 10 年后中国激光雷达技术持较为乐观的态度，认为中国未来激光雷达技术会在全球处于领先水平；但 40.44%的受调查者持较为保守的态度，认为 10 年后中国激光雷达技术依旧处于中等水平。

However, 57.60% of the respondents are optimistic about China's LiDAR technology 10 years from now, believing that China will lead the world in LiDAR technology in the future. However, 40.44% of the respondents hold a more conservative attitude, believing that China's LiDAR technology is still at the medium level after 10 years.



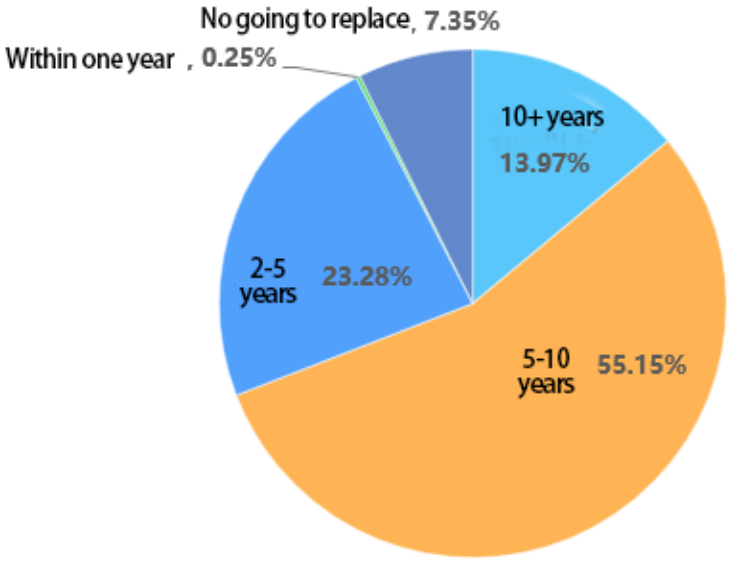
Respondents' Opinion on LiDAR industry in China in 10 years

3.2 光源 Light Source

3.2.1 1550nm 波长的激光器更受青睐 the 1550nm laser is perferred

据麦姆斯咨询介绍，大多数激光雷达制造商正在使用波长为 905nm 的光源，因为与 1550nm 的光源相比，它们的成本更加合理，所以获得大量采用。但 1550nm 的光源人眼安全性高，功率更高，可探测距离更远，因此在本次调查中，1550nm 激光器更为受到青睐。57.84%的受调查者认为未来 5 年内更看好 1550nm 波长的激光光源，并有 55.15%的受调查者认为 1550nm 激光器将在未来 5~10 年内取代 905nm 激光器的主导地位。

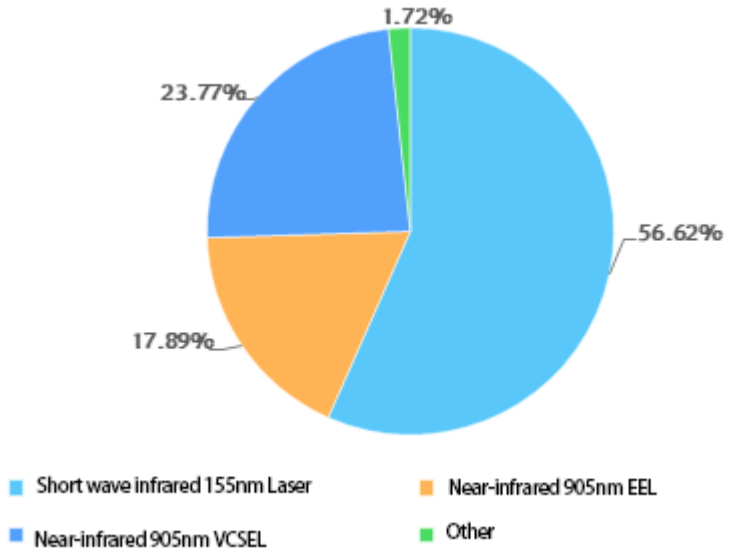
According to MEMS Company, most LiDAR manufacturers are using sources with wavelengths of 905nm, which are widely adopted because they are more affordable than sources with 1550nm. However, the 1550nm light source has higher human eye safety, higher power and longer detection distance, so in this survey, the 1550nm laser is preferred. 57.84% of respondents believe that the 1550nm laser source will be more favorable in the next five years, and 55.15% believe that the 1550nm laser device will replace the dominant position of the 905nm laser in the next five to 10 years.



Prediction on when 1550nm laser light source replace 905nm

而在目前的热门激光光源器件的选择中，有 56.62%的受调查者认为短波红外 1550nm 激光器将成为激光雷达的主流光源，23.77%的受调查者看好垂直腔面发射激光器（VCSEL），相比之下，近红外 905nm 边发射激光器（EEL）的地位逐渐降低，只有 17.89%的受调查者看好 EEL。

And among the present popular laser light source device of choice, with 56.62% of respondents believe that short wave infrared 1550 nm laser light source will become the mainstream of the laser radar, 23.77% of respondents favored the vertical-cavity surface-emitting laser (VCSEL), by contrast, the 905 nm edge emitting laser (EEL) status gradually reduced, only 17.89% of respondents favored EEL.



Survey on main light source on LiDAR on Automotive

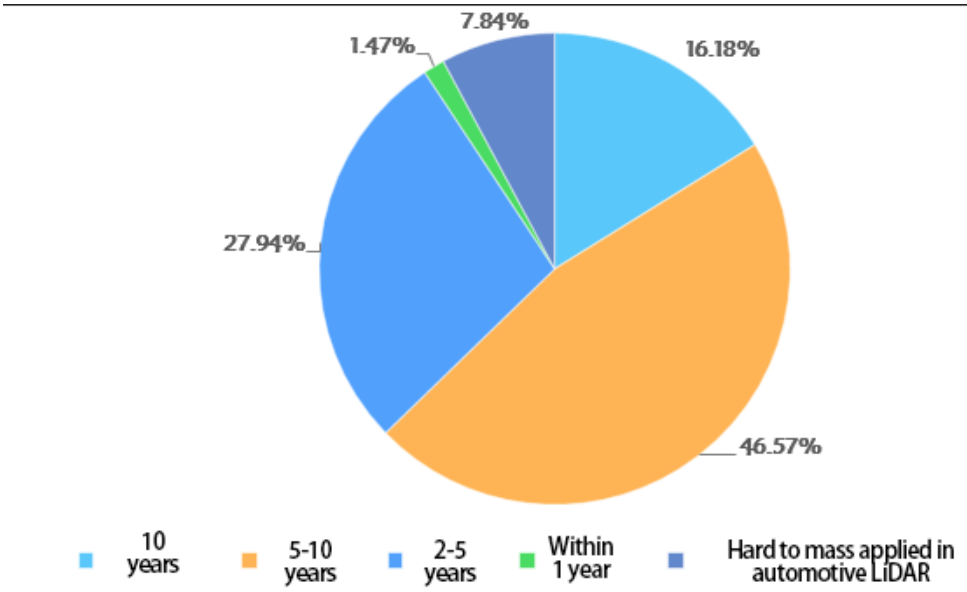
3.2.1 VCSEL 应用于车载激光雷达呼声高 High voice for applying VCSEL into Vehicle-mounted LiDAR

车载激光雷达需要足够远的探测距离，对激光的功率有较高的要求。就功率而言，边发射激光器（EEL）目前有一定的优势。但是，随着高功率 VCSEL 的研发进步，及相应波段的高灵敏度接收器的逐渐成熟，采用 VCSEL 的车载激光雷达已成为业界研发热点。

在本次调查中，约一半的受调查者认为 VCSEL 将在 5~10 年成熟应用于激光雷达。

Vehicle-mounted LiDAR requires a detection range far enough to meet the high requirement of laser power. In terms of power, the edge-emitting laser (EEL) currently has some advantages. However, with the development and progress of high-power VCSEL and the gradual maturity of high-sensitivity receivers in corresponding bands, the on-board LiDAR using VCSEL has become a research and development hotspot in the industry.

In this survey, about half of the respondents believe that VCSEL will be used in LiDAR in 5~10 years.



Prediction on Maturity of VCSEL

2017 年，苹果（Apple）公司发布了十周年纪念版的产品：iPhone X，集成了基于 VCSEL 技术的 3D 传感功能。iPhone X 智能手机采用了三种不同的 VCSEL 芯片（用于 Face ID 的 3D 摄像头、接近传感器），进而促使 VCSEL 市场呈现爆炸式增长势头——2017 年 VCSEL 整体市场规模达到 3.3 亿美元。在此背景下，2017 年启动的新一轮 VCSEL 市场增长浪潮将持续至未来五年，相关商业机会有可能增加十倍以上。与此同时，VCSEL 正努力进入其它一些批量应用领域，汽车激光雷达则是最具潜力的应用。

In 2017, Apple released its 10th anniversary product: the iPhone X, which integrates 3D sensing based on VCSEL technology. The iPhone X smartphone is powered by three different VCSEL chips (the 3D camera for the Face ID, the proximity sensor) that have exploded the VCSEL market, which totaled $330 million in 2017. In this context, the new round of VCSEL market growth wave launched in 2017 will continue to the next five years, and related business opportunities are likely to increase more than tenfold. At the same time, VCSEL is trying to get into other mass applications, with automotive LiDAR being the most promising.

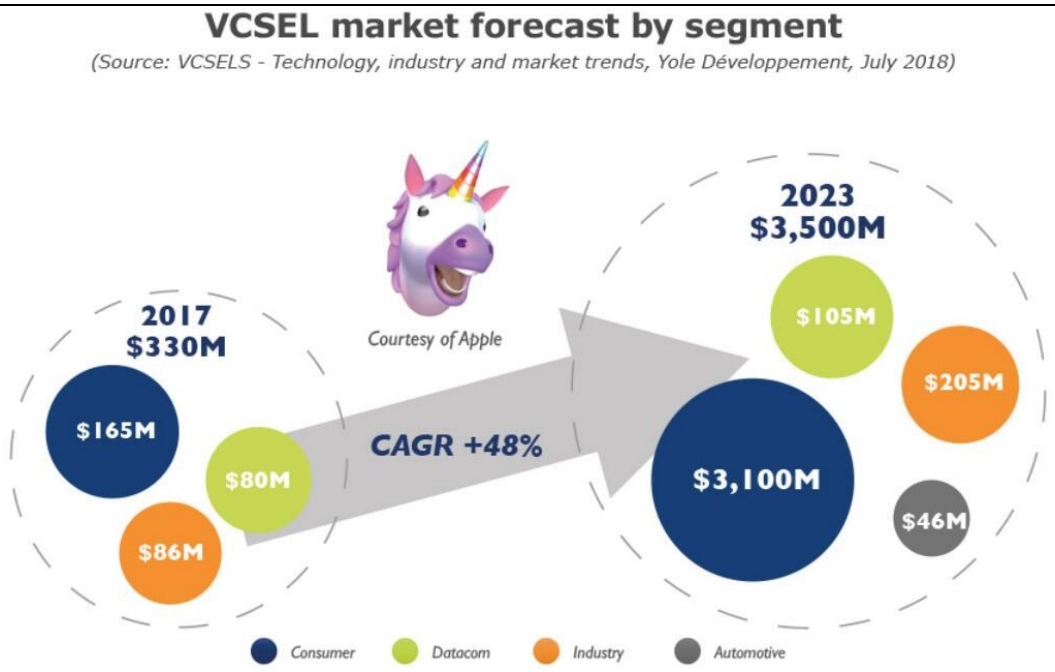
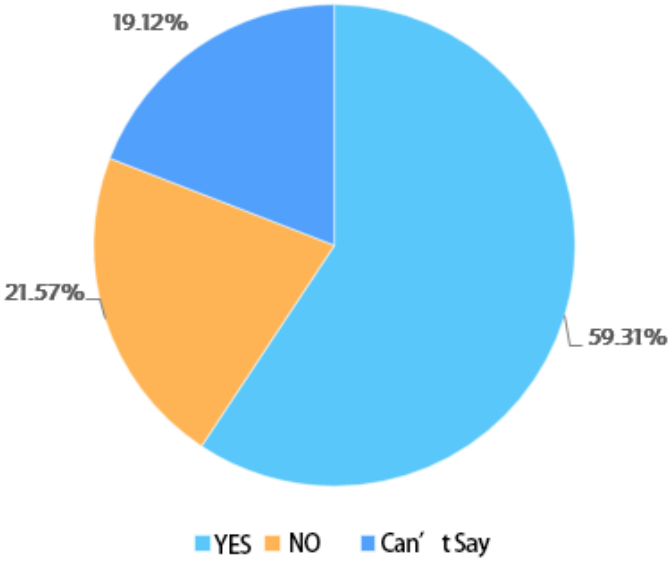


图 30：VCSEL 的汽车市场将从 2017 年的 0 增长至 2023 年的 4600 万美元

（来源：《VCSEL 技术、产业和市场趋势》）

在本次调查中，有 59.31%的受调查者认可汽车激光雷达将再一次引发 VCSEL 投资热潮。或许，继智能手机 3D 成像和传感为 VCSEL 产业带来的投资热潮后，激光雷达又将继续推动 VCSEL 产业的技术进步，对应的投资热潮也随之而来！

In this survey, 59.31% of respondents agree that automotive LiDAR will once again trigger the VCSEL investment boom. Perhaps, after the investment boom brought by smartphone 3D imaging and sensing for VCSEL industry, LiDAR will continue to promote the technical progress of VCSEL industry, and the corresponding investment boom will follow!



Whether LiDAR will trigger another investment trend on VCSEL

3.3 光束操纵元件 Beam control element

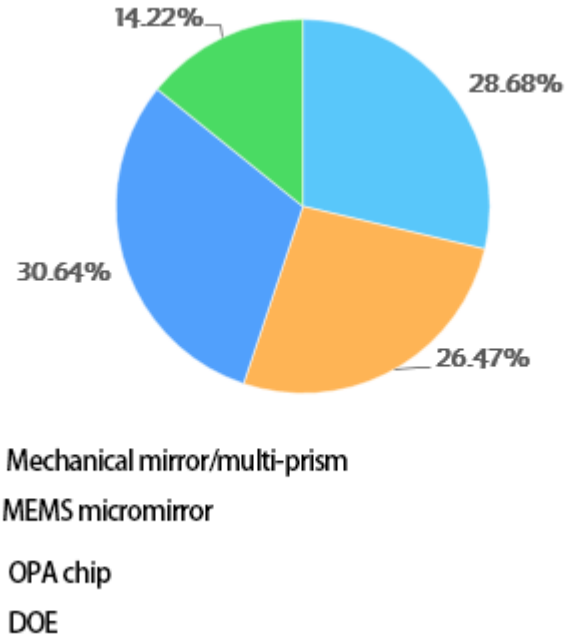
据麦姆斯咨询在报告《激光雷达技术及核心元器件-2019 版》中介绍，“机械式、MEMS、OPA、Flash”等这些名词，均是从激光雷达的“光束操纵”维度进行分类的。激光雷达采用的光束操纵元件有机械式摆镜/多棱镜、MEMS 微镜（又称 MEMS 扫描镜、MEMS 微振镜）、OPA 芯片、光学衍射元件（DOE）等。而 Flash 激光雷达将目标场景中充满光，而照明区域与探测器的视场相匹配，通过面阵探测器获得目标的距离和像素信息，无需额外的光束操纵组件。

The terms "mechanical, MEMS, OPA, Flash" are all classified from the "beam manipulation" dimension of LiDAR, according to the report "LiDAR technology and core components -2019 edition" by MEMS Consulting. The beam operating elements used in LiDAR include mechanical pendulum mirror/multi-prism, MEMS scanning mirror (also known as MEMS scanning mirror, MEMS microgalvanometer), OPA chip, optical diffraction element (DOE) and so on. Flash LiDAR fills the target scene with light, and the lighting area matches the detector's field of view, and obtains the distance and pixel information of the target through the array detector, without the need for additional beam manipulation components.

3.3.1 技术难度分析 Technical difficulty analysis

机械式摆镜/多棱镜容易磨损、装配和调试难度高；MEMS 微镜受镜面尺寸限制等问题，性能暂时难以满足车规要求；OPA 芯片纳米级加工难度高；DOE 对纵向尺度上的准确性要求极高，需要在深度和宽度两个不同维度进行精确控制。在本次调查中，受调查者认为实现机械式摆镜/多棱镜、MEMS 微镜和 OPA 芯片在激光雷达中的量产的技术难度均不小，分别为 28.68%、26.47%和 30.64%。

Mechanical mirror/multi-prism is easy to wear, difficult to assemble and debug; MEMS scanning mirror is limited by mirror size and other problems, the performance temporarily difficult to meet the requirements of car regulations; The nanoscale processing of OPA chip is difficult. The DOE requires extremely high accuracy on the vertical scale, requiring precise control in two dimensions, depth and width. In this survey, respondents believe that it is difficult to realize mass production of mechanical mirror/multi-prism, MEMS scanning mirror and OPA chip in LiDAR, which are 28.68%, 26.47% and 30.64% respectively.

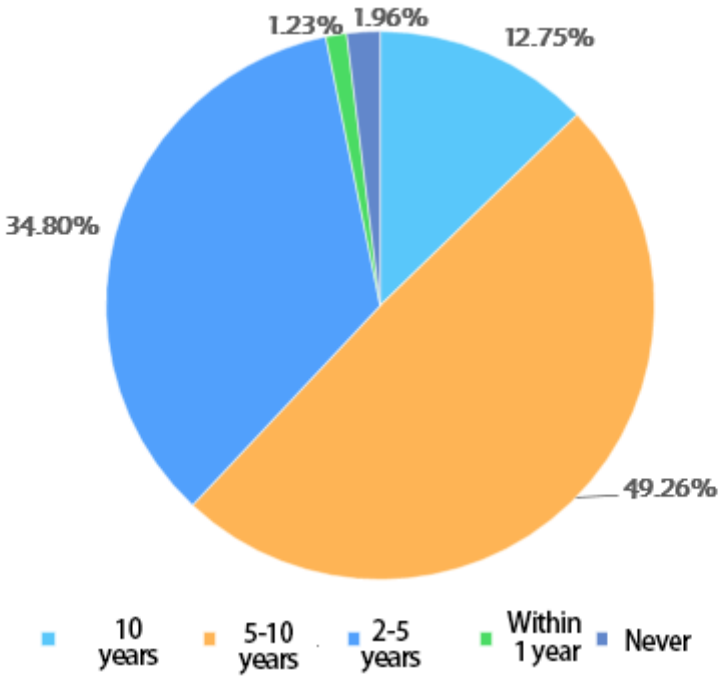


Most difficult realizing beam control component

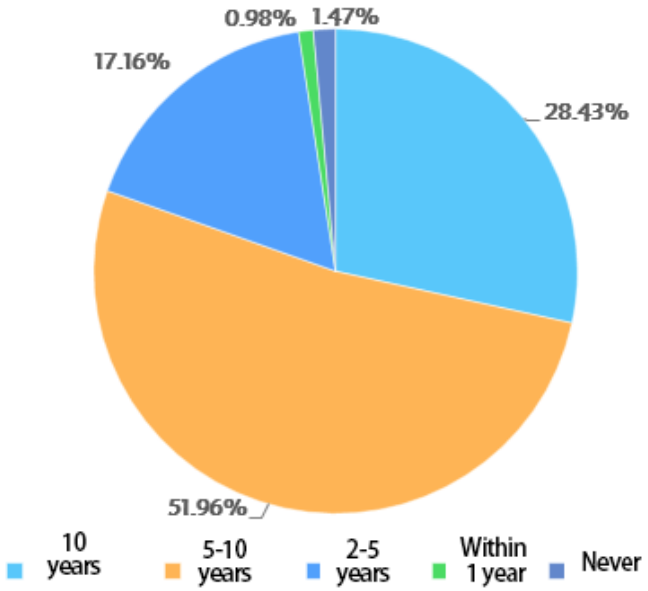
那么，MEMS 微镜何时将在激光雷达量产落地？根据我们的调查，有 34.80%的受调查者认为将在 2~5 年内发生，有 49.26%的受调查者认为将在 5~10 年内发生。相比之下，OPA 芯片量产落地于激光雷达的时间点被认为晚于 MEMS

微镜。在本次调查中，认为 OPA 芯片将在 2~5 年量产落地于激光雷达的比例仅 17.16%，更多的受调查者倾向于在未来 5~10 年内量产落地(比例为 51.96%)，而认为需要 10 年以上的受调查者比例也是 MEMS 微镜的两倍。

So, when will the MEMS scanning mirror be mass-produced in LiDAR? According to our survey, 34.80% of the respondents think it will happen in 2 to 5 years, and 49.26% think it will happen in 5 to 10 years. By contrast, OPA chips are thought to land on LiDAR at a later time than MEMS scanning mirrors. In this survey, only 17.16% believe that the OPA chip will be mass-produced and land on LiDAR in 2~5 years, and more respondents tend to be mass-produced and land on LiDAR in the next 5~10 years (51.96%), and the proportion of respondents who believe that it will take more than 10 years is also twice than that of MEMS scanning mirrors.



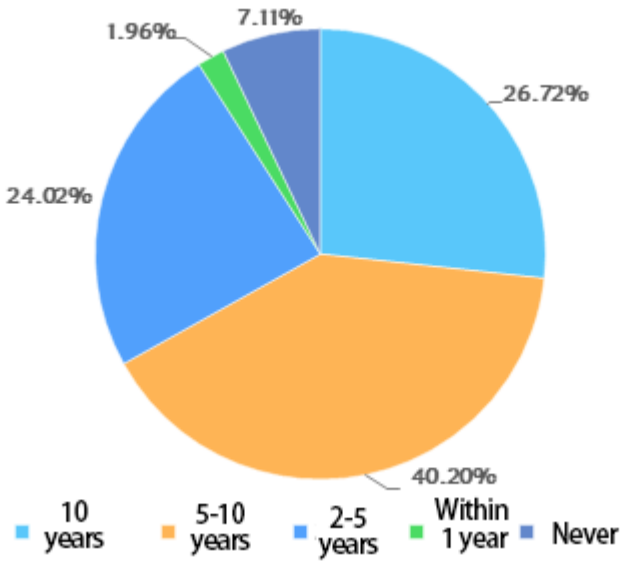
MEMS scanning mirror Mass Production Time



OPA Chip Mass Production Time for LiDAR

Flash 激光雷达虽然无需任何光学操纵元件，但难以同时满足远近成像的要求。作为全固态激光雷达，Flash 激光雷达有着最天然的优势。随着探测器技术的成熟，或是未来最有潜力的激光雷达技术路线。

Although the Flash LiDAR does not need any optical control elements, it is difficult to meet the requirements of near and far imaging. As an all-solid state LiDAR, Flash LiDAR has the most natural advantage. As the detector technology matures, Flash LiDAR may be the most potential LiDAR technology route in the future.



Flash LiDAR Mass Production Time

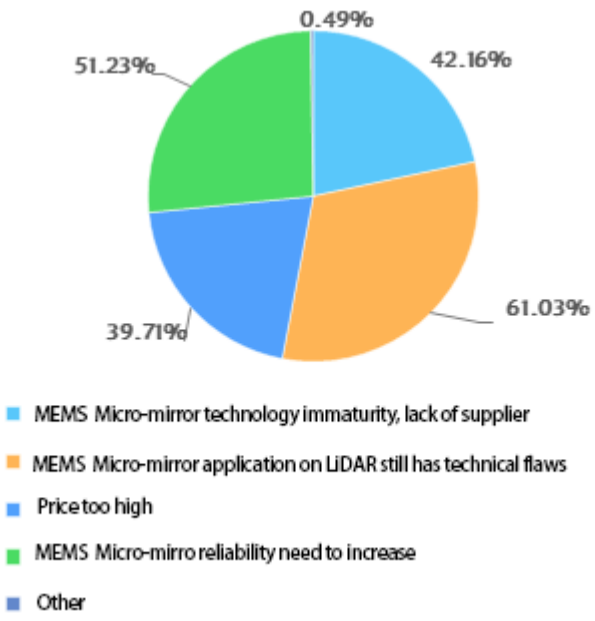
3.3.2 MEMS 微镜 MEMS scanning mirror

今年，麦姆斯咨询在一篇原创文章《2019 年会成为 MEMS 激光雷达技术路线元年吗？》中对 MEMS 微镜用于激光雷达的问题做了详细分析。比如镜面尺寸难以做大，价格高，光学口径、扫描角度，视场角受限等问题。

本次调查也重点调查了大家对 MEMS 微镜应用于激光雷达的看法。受调查者对 MEMS 微镜本身技术不成熟，缺乏供应商；MEMS 微镜应用在汽车激光雷达上还有技术问题未解决；应用于汽车激光雷达的 MEMS 微镜价格高昂；MEMS 微镜的可靠性有待提高等问题达成了较为统一的共识。

This year, MEMS Consulting published an original article titled "will 2019 be the first year of MEMS LiDAR technology?"In this paper, the application of MEMS scanning mirror to LiDAR is analyzed in detail. For example, problems include that mirror size is difficult to make large, high price, optical aperture, scanning Angle, field of view Angle is limited, and so on.

This survey also focused on the MEMS scanning mirror application in LiDAR views. Respondents have reached a consensus on the fact that MEMS scanning mirror technology are not mature, lacks of suppliers, exists some technical problems, owns expensive price and need to improve the reliability.



Main problems on MEMS Scanning mirror’s application on LiDAR

激光雷达厂商想要成功研发 MEMS 激光雷达，最快捷的路径是哪条？大家似乎更倾向于“拿来主义”：54.41%的受调查者支持收购成熟的 MEMS 微镜企业为我所用；27.21%的受调查者建议直接外购 MEMS 微镜产品；只有 17.16%的受调查者同意自力更生，建立自研团队，定制开发 MEMS 微镜。

What is the fastest way for LiDAR manufacturers to successfully develop MEMS LiDAR? People seem to be more inclined to "adopt" : 54.41% of respondents support the acquisition of mature MEMS scanning mirror enterprises for our use; 27.21% of respondents suggested direct outsourcing of MEMS scanning mirror products; Only 17.16% of the respondents agreed to be self-reliant and set up their own research team to develop customized MEMS scanning mirrors.

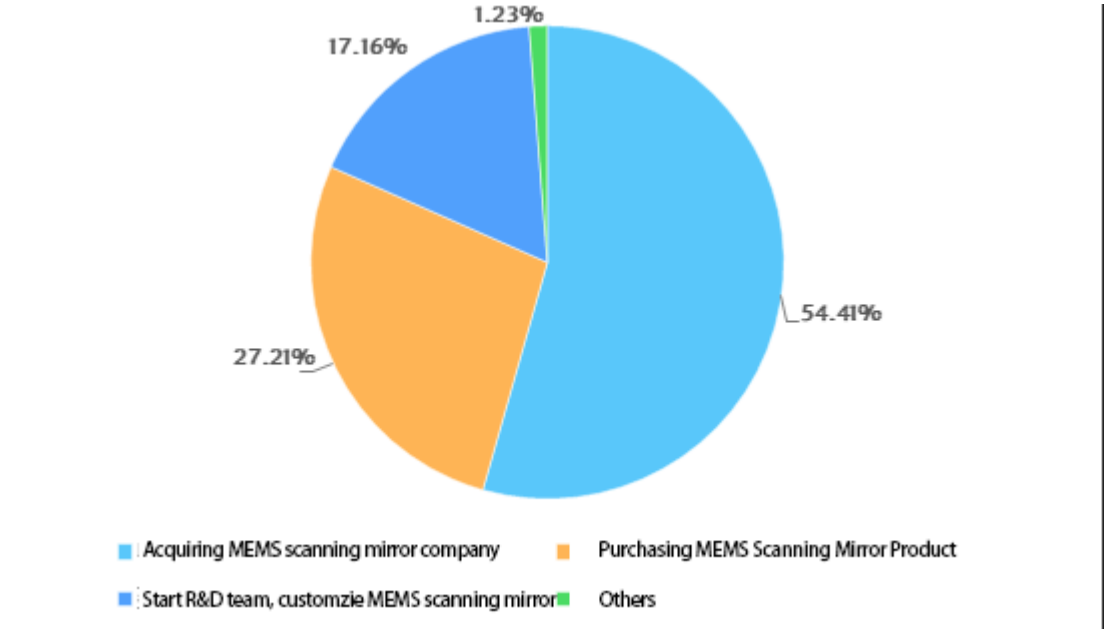


图 37：研发 MEMS 激光雷达的最快捷路径

在中国，近些年 MEMS 微镜企业发展迅速，如西安知微传感、台湾 Opus、苏州希景科技、常州创微科技等。这些企业也在积极和激光雷达厂商合作开发适用于车载激光雷达的 MEMS 微镜。

In China, MEMS scanning mirror enterprises have developed rapidly in recent years, such as xi 'an Zhisensor, Taiwan Opus, Suzhou Silicon Vision Microsystem, Changzhou Micro Innovation and so on. These enterprises are also actively cooperating with LiDAR manufacturers to develop MEMS scanning mirrors suitable for vehicle-mounted LiDAR.

3.3.3 OPA 芯片 OPA Chip

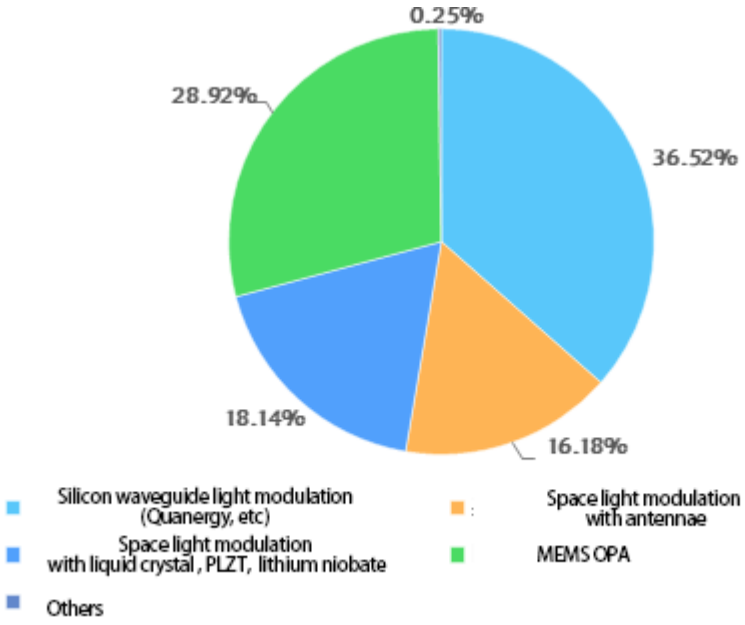
OPA 芯片的制造工艺有多种选择，如以美国激光雷达企业 Quanergy 为代表的硅波导光调制，还有采用纳米天线的空间光调制和采用液晶、锆钛酸铅镧陶瓷 (PLZT)、铌酸锂等的空间光调制，以及最近报道的 MEMS OPA 技术。目前，还没有哪种技术在 OPA 激光雷达中真正胜出，那么大家持何种观点?

在本次调查中，有 36.52%的受调查者依然支持传统的硅波导光调制技术，也有 28.92%的受调查者对新兴的 MEMS OPA 技术充满了信心!

There are many options for OPA chip manufacturing, such as silicon waveguide light modulation represented by Quanergy, an American

LiDAR company, space light modulation using nanomaterials and space light modulation using liquid crystal, PLZT, lithium niobate, and MEMS OPA technology reported recently. So far, no technology has really won out over OPA LiDAR, so what do you think?

In this survey, 36.52% of respondents still support the traditional silicon waveguide light modulation technology, and 28.92% are full of confidence in the emerging MEMS OPA technology!

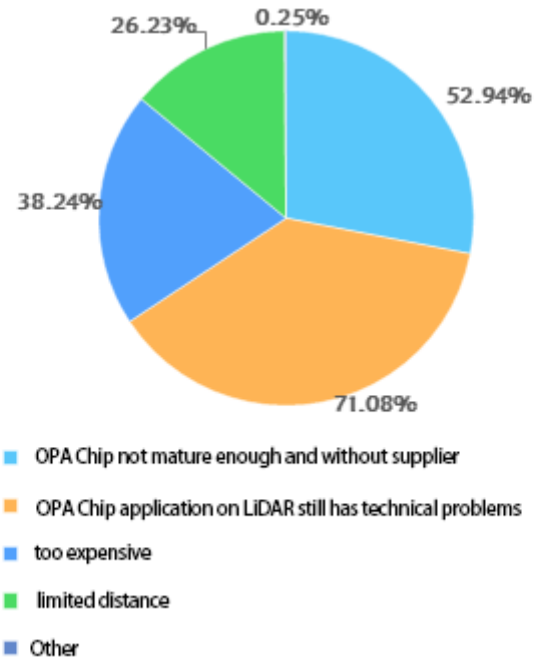


OPA Implement Solution

谈及 OPA 芯片应用到 OPA 激光雷达面临的主要问题，虽然硅波导光调制和空间光调制技术都不是新兴技术，但是应用到激光雷达上还有许多技术问题没有解决，有高达 71.08%的受调查者对此投赞成票。其次，52.94%的受调查者认为 OPA 芯片本身技术不成熟，缺乏供应商。当然，价格高昂、探测距离受限等也是不可回避的问题。

Talking about the main problems facing the application of OPA chip to OPA LiDAR, although neither silicon waveguide light modulation nor space light modulation technology is an emerging technology, there are still many technical problems to be solved in the application to LiDAR, and up to 71.08% of the respondents voted in favor of this. Secondly, 52.94% of the respondents believe that OPA chip itself is not mature in technology and lacks of suppliers. Of course, high price and limited

detection range are also unavoidable problems.



The problems from OPA Chip to OPA LiDAR

3.4 光电探测器 Optical Detector

905nm 雪崩光电二极管（APD）是目前开发激光雷达的典型元器件，单光子雪崩二极管（SPAD）和硅光电倍增管（SiPM）等元器件预计将在下一代激光雷达产品中得到应用。905nm 雪崩光电二极管是否会被快速取代？调查结果是否定的。只有 2.45%的受调查者认为 905nm 雪崩光电二极管将在 1 年内失去优势，认为其仍然会在激光雷达应用保持 2~5 年、5~10 年和 10 年以上优势的受调查者比例分别为 38.97%、45.83%和 12.75%。

905nm avalanche photodiode (APD) is a typical component of laser radar currently developed. Single-photon avalanche diode (SPAD) and silicon photomultiplier tube (SiPM) are expected to be used in the next generation of LiDAR products. Will 905nm avalanche photodiode be quickly replaced? The findings are negative. Only 2.45% of the respondents believe that 905nm avalanche photodiode will lose its advantage in one year, and 38.97%, 45.83% and 12.75% of the respondents believe that it will still maintain its advantage in LiDAR application for 2-5 years, 5-10 years and more than 10 years respectively.

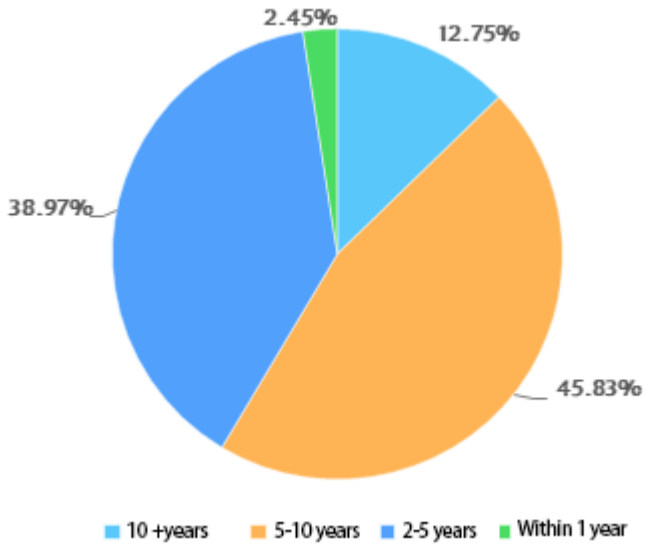
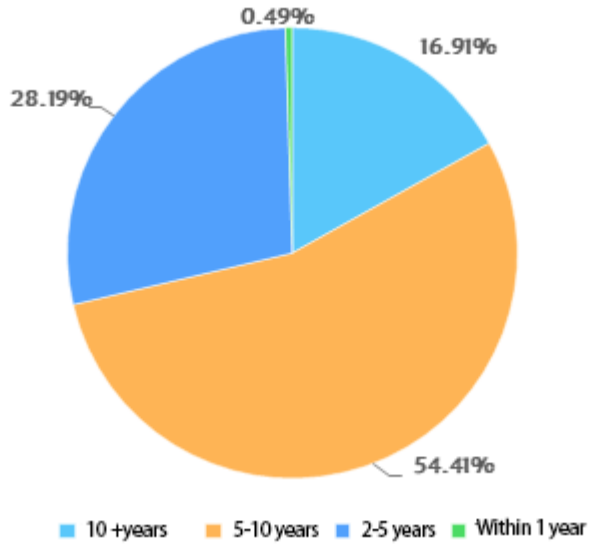


图 40：905nm 雪崩光电二极管（APD）在激光雷达的优势保持时间

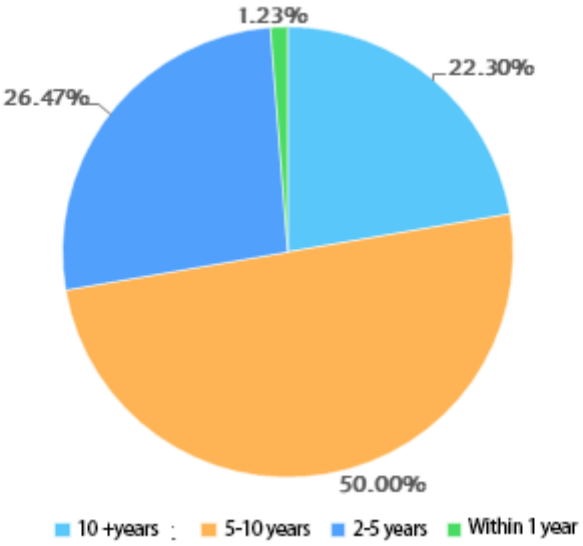
Duration of 905nm APD’s advantages on LiDAR

单光子雪崩二极管（SPAD）工作在盖革模式。当偏置电压高于其雪崩电压时，增益迅速增加，单个光子吸收即可使探测器输出电流达到饱和，从而实现对光子的计数。而硅光电倍增管（SiPM）由多个工作在盖革模式的 SPAD 阵列组成，具有弱光探测应用的明显优势。SPAD/SiPM 技术的成熟也将为激光雷达带来成本、体积等优势。

Single photon avalanche diode (SPAD) works in Geiger mode. When the bias voltage is higher than its avalanche voltage, the gain increases rapidly, and single photon absorption can make the output current of the detector reach saturation, so as to realize the counting of photons. The silicon photomultiplier tube (SiPM) is composed of several SPAD arrays working in Geiger mode, which has obvious advantages in low-light detection applications. The maturity of SPAD/SiPM technology will also bring cost, volume and other advantages to LiDAR.



Prediction on when SPAD mass application on LiDAR

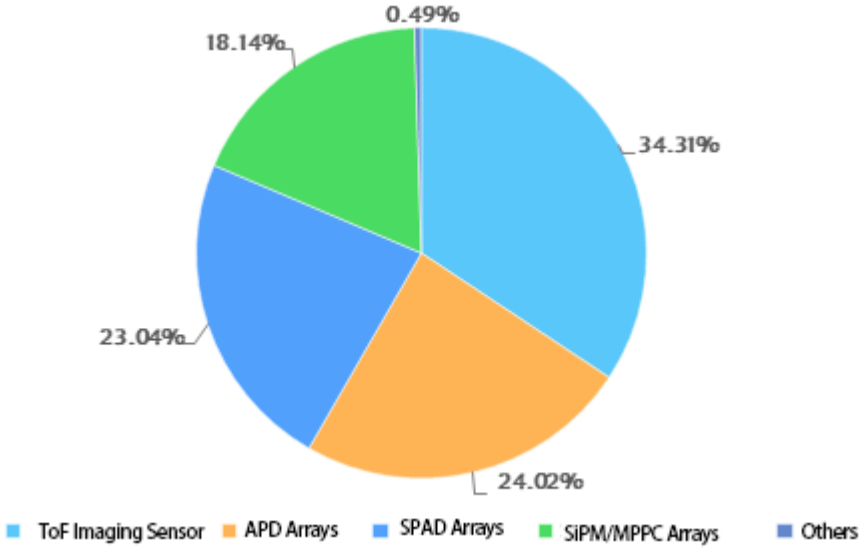


Prediction on when SiPM mass application on LiDAR

对于 Flash 激光雷达，需要线阵/面阵光电探测器接收从物体反射回来的面光源信号，可选用的光电探测器有 ToF 图像传感器、APD 阵列、SPAD 阵列、SiPM/MPPC 阵列等。ToF 图像传感器可以提供视角范围内场景的整个分辨率的距离景深数据，成为 Flash 激光雷达的主要选择之一。在本次调查中，有 34.31%的受调查者选择了 ToF 图像传感器，认为该技术更为成熟。

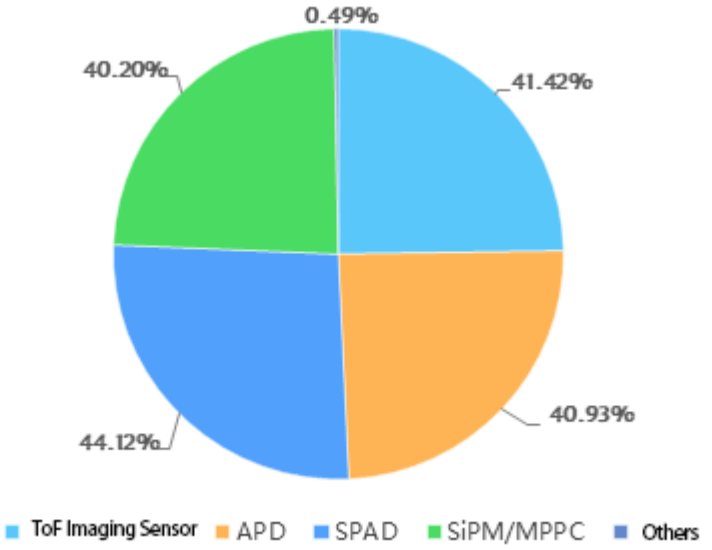
For Flash LiDAR, linear array/planar array photodetector is required to receive the surface light source signal reflected from the object. The optional photodetectors include ToF image sensor, APD array, SPAD array,

SiPM/MPPC array, etc. The ToF image sensor can provide the range depth of field data of the whole resolution of the scene within the perspective range, becoming one of the main choices of Flash LiDAR. In this survey, 34.31% of respondents chose ToF image sensor, believing that this technology is more mature.



Flash LiDAR Detector

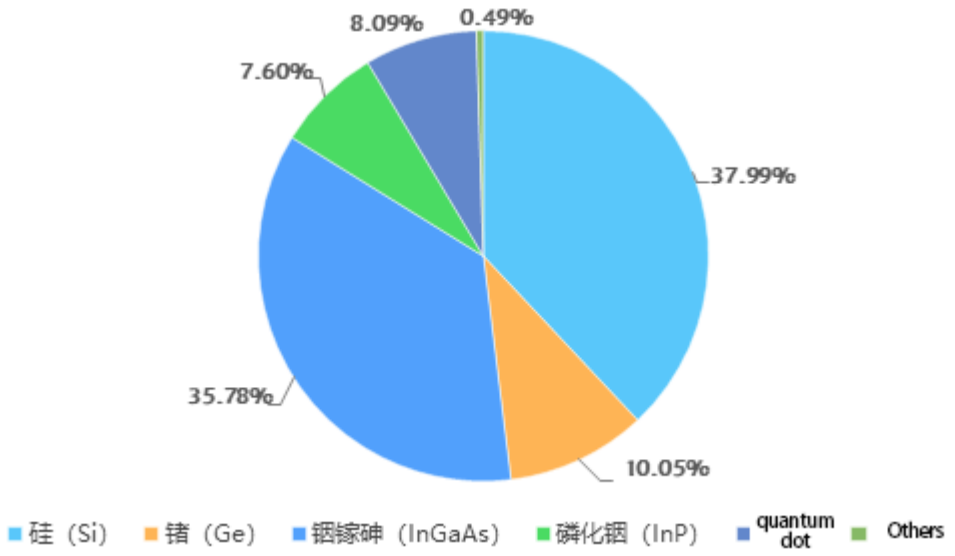
就激光雷达整体市场来讲，受调查者对各种光电探测器“各有所爱”，因为各种技术路线对探测器需求各不相同。在“就激光雷达整体市场来讲，您看好的光电探测器？”这个调查中，结果显示各种器件不分伯仲，都有机会分得一杯羹。In terms of the overall market for LiDAR, the respondents have their own preference for various photodetectors, because different technology routes have different requirements for detectors. In the survey," Are you optimistic about photodetectors In terms of the overall market for LiDAR?" the results show that all kinds of devices are equally likely to get a slice of the pie.



Detectors applying on LiDAR

目前用于激光雷达光电探测器的材料以硅(Si)和铟镓砷(InGaAs)为主，前者主要用于对近红外波段如 905nm 激光源的探测，而后者主要用于对短波红外波段如 1550nm 激光源的探测。而锗（Ge)、磷化铟（InP)、量子点等材料也在激光雷达光电探测器上也有应用或研发。从本次的调查中，可以看到受调查者对未来 10 年的主流光电探测器材料的选择，依然认同硅（Si）和铟镓砷（InGaAs)，选择比例分别为 37.99%和 35.78%。

Currently, the materials used for photodetectors of LiDAR are mainly silicon (Si) and indium gallium arsenic (InGaAs). The former is mainly used for the detection of near-infrared bands such as 905nm laser source, while the latter is mainly used for the detection of short-wave infrared bands such as 1550nm laser source. Germanium (Ge), indium phosphide (InP), quantum dots and other materials are also used or developed in LiDAR photodetector. From this survey, it can be seen that respondents still agree with the choice of silicon (Si) and indium gallium arsenic (InGaAs) for the mainstream photoelectric detector materials in the next 10 years, with the proportion of 37.99% and 35.78% respectively.



Substrate material on detectors

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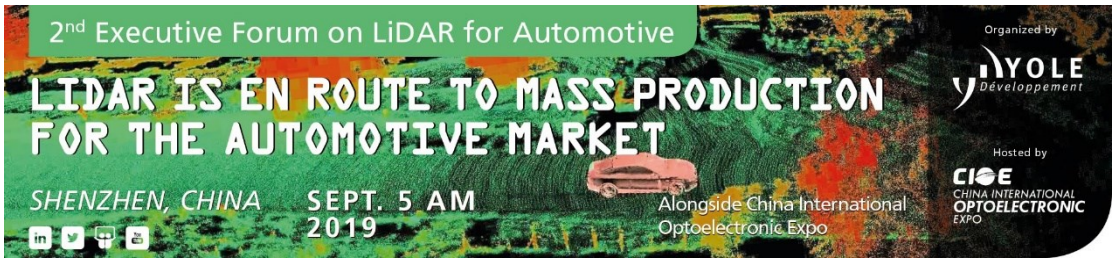

第二届国际汽车激光雷达创新论坛 – 汽车市场成就激光雷达量产

The 2nd Executive Forum on LiDAR for Automotive - LiDAR is en route to mass production for the automotive market

2019 年 9 月 5 日上午 深圳会展中心 5 楼菊花厅
Sept. 5 AM, 2019，Chrysanthemum Hall, 5th Floor, SZCEC

继 2017 年激光雷达已在集成在奥迪 A8 上后，去年由于 Waymo 自动汽车在美国凤凰城上线后，激光雷达如今已实现上路。自动驾驶注定将掀起汽车制造领域的下一波浪潮。包括汽车制造商、一级供应商和激光雷达生产商在内，众多自动驾驶技术上下游环节中的企业，都受到这一趋势波及。激光雷达的供应链系统，正在为未来两年的汽车激光雷达量产，做量产和销售目标的准备。2020，蓄势待发。
第二届国际汽车激光雷达创新论坛将介绍激光雷达行业的应用和技术，尤其是面向汽车的解决方案。我们诚邀各位再次与会，共同探讨推动汽车行业升级的核心技术——激光雷达技术的发展。点击查看会议日程。
After a successful first edition, Yole Développement is proud to collaborate once again with the China International Optoelectronic Expo (CIOE) to organize the Second Executive Forum on LiDAR for Automotive. It will take place on September 5, 2019 in Shenzhen, alongside the 21st CIOE. This event presents applications and technologies within the LiDAR industry, and more specifically, automotive-oriented solutions.
With the integration of LiDAR in the Audi A8 in 2017, and the introduction of Waymo’ s robotic car service in 2018 in Phoenix, Arizona, LiDARs are now on the roads. Autonomous driving is expected to be one of the next big things in the automotive industry. Several companies, including car manufacturers, Tier 1 suppliers, and LiDAR players, are preparing for mass production of automotive LiDAR with commercialization targets for 2020 and 2021. The automotive LiDAR supply chain is getting ready. Join us in Shenzhen and participate in discussions about this key technology for the automotive industry!

2019 Speakers: Innoviz, Robosense, Valeo, First Sensor, System Plus Consulting, Yole Développement.. In total 7 high level presentations!

Full Agenda