Chip-scale packages (CSPs) are new to the LED industry, but are the mainstay of the traditional semiconductor industry, where they improve reliability, thermal management and enable smaller packages.

CSP LEDs can be less than a tenth of the size of high and middle power LEDs, increasing power density and simplifying integration into final products. This new architecture can also lower thermal resistance, improve reliability and widen viewing angles compared to other traditional packages.

However, there are also several challenges to overcome at the device manufacturing and module integration levels. These include color uniformity, chemical stability, given there is little to no sealing off from the external environment, and control of optical properties like the radiation pattern.

In this context, Yole Développement estimates that CSP LED modules represented less than 1% of the LED module business in 2016. However, with strong potential in multiple applications and the lighting industry getting experience with integrating such technology, we forecast a market share of nearly 6% by 2021.

This report provides a comprehensive analysis of CSP LED devices, with analyses including: chip and package technology, manufacturing processes, related costs/prices, industry and market trends. The report details deeply analyses CSP LED lighting module design, with focuses including: optical design, thermal and electrical management and precautions for CSP LED integration.
matrix headlamps will include CSP LEDs to increase matrix resolution, enhance driver vision and improve Advanced Front Light Systems (AFLS) in combination with cameras. In this report, Yole Développement maps the CSP LED application landscape. It analyses CSP LED lighting module performance in general lighting applications, identifying opportunities, describing case studies, and comparing positioning against other module technologies.

**SIMPLIFIED MANUFACTURING PROCESS IMPACTS THE SUPPLY/VALUE CHAIN**

CSP LED technology eliminates some package assembly and die attach stages. This is likely to benefit to LED chip manufacturers, who can develop packages and supply them directly to LED module manufacturers more easily, bypassing their traditional customers, and so increasing their profits. Vertically integrated LED manufacturers can also decrease their packaging costs. However, adopting the technology requires development of new expertise, modifying the traditional packaging landscape. For example, phosphor and encapsulant deposition processes will move from dispensing to phosphor sheet/film deposition or molding. This evolution affects equipment and material suppliers, who have to develop new solutions.

Operationally, Lumileds was the first company to commercialize LEDs in CSP format in 2013. The company was rapidly followed by several other players, mostly Taiwanese. But some others, like Osram, still have doubts about the necessity of such technology, and instead are positioned toward traditional middle and high power LEDs, including COBs.

This debate is also relevant at the LED module level, where CSPs cause some difficulties. For example, during PCB design, special care should be given to copper traces and solder masks for optimum performance. Some critical properties, like their small soldering surfaces and sideways light emission, may impact module integration. And while the benefits of CSP LEDs are not yet clear for them, they question the real opportunity of this solution.

This report provides insights into the changes in manufacturing and integration processes CSP LEDs bring, and potential consequences on the supply/value chain. Additionally, it analyses real opportunities for such technologies based on simulations and case studies.

**COMPANIES CITED IN THE REPORT** (non exhaustive list)

Apple, AT&S, Audi, BMW, BREE Optronics, Bright LED, Carclo, Cree, Dow Corning, Edison Opto, Epistar, ETI, Everlight, Fraen, Genesis Photonic Inc., Haueusermann, Hakko, Harvatek, Honglitronics, Huawei, ITRI, Jufei, Kathod, Kingbright, Ledil, Lextar, LG, Lite On, Luminus Devices, Mason, Maven Optronics, Mercedes-Benz, MLS, Nationstar, Nichia, Oasis, Opel, Optotech, Osram, Philips Lumileds, Plessey Semiconductors, Refond, Samsung, Sanan, Seoul Semiconductors, Toshiba, Toyoda Gosei, Tridonic, Trilux, TSMC, Unistars Mercury, Unity Opto, Wellypower...
TABLE OF CONTENTS (complete content on i-Micronews.com)

About the authors of the report 5
Report objectives 6
Companies cited in this report 7
Glossary 8
Methodology 9
Executive summary 10
Status of the LED industry and recent trends 40
> Status of the LED industry including
  - Introduction - Segmentation of packaged LEDs
  - History of the LED industry
  - Package LED revenue forecast - Split by application
  - 2015 and 2016 in a nutshell
  - Future trends
  - LED market trends
> Recent trends in the LED industry
  - Overview
  - Product diversification (Level 1)
  - Application diversification - Automotive lighting
  - Product diversification (Level 2) - UV LEDs
  - Vertical integration - LED module
  - Conclusion

CSP LED application landscape 61
> Overview
> Flash
> Backlighting
> General lighting
> Automotive lighting

CSP LED devices 68
> Introduction to CSP LED devices
  - Definition
  - Benefits
> CSP LED device family description
  - Introduction
  - Size criterion
  - Power density criterion
  - CSP or not CSP?
  - Power criterion
> CSP LED device technology
  - Differences from other packages
  - CSP LED structures
  - CSP LEDs in LED package proliferation
  - Flip Chip CSP LED vs high power-type LEDs
  - Wafer Level CSP LEDs vs high power-type LEDs
  - Vertical thin film CSP LEDs vs high power-type LEDs
  - Flip Chip packaged CSP LEDs vs high power-type LEDs
> CSP LED device manufacturing process
  - Conventional LED manufacturing process
  - Flip Chip CSP LED manufacturing process
  - Wafer Level CSP LED manufacturing process
  - CSP LEDs vs traditional LED modules
  - Impact on supply/value chain
> CSP LED device cost/price
  - Potential for cost reduction
  - The case of CSP architecture for low and middle power LEDs
  - The case of CSP architecture for high power LEDs
  - Price positioning of CSP LEDs vs. traditional LEDs
  - Price positioning of CSP LED modules vs. traditional modules
> CSP LED device industry
  - Key players identified
  - Highlights of US and European Players
  - Highlights of Japanese Players
  - Highlights of Korean Players
  - Highlights of Taiwanese and Chinese Players
  - Trends - Flow chart comparison between standard, CSP and COB LEDs
> CSP LED market
  - CSP LED market volume (2012 - 2021)

CSP LED lighting module 112
> Chip singulation
  - Objectives, methodology and synthesis
  - From device characteristics to performance in applications
  - System design and performance assessment
  - Impact of CSP LED device on system/module design
  - CSP LED system/module performance in application
> Definition and types of LED lighting modules
  - Definitions
  - LED module in the overall LED value chain
  - The different types of LED modules - Taxonomy
  - The different types of LED modules - Positioning
> Main functions in LED lighting modules
  - System structure
  - Parameter interdependence
> Optical design of CSP LED lighting modules
  - Optical management inside LED devices
  - CSP LED optical behavior
  - Sideways light emission of a package-free CSP LED device
  - Influence of CSP LED package on emission profile
  - Light emission profile
  - Light Emitting Surface (LES) and beam angle
  - Optical management in the application
  - Luminance control
  - Optical integration - Single LED and arrays
  - Shadowing effect in close pack arrangements
  - Main consequences and opportunities of the optical properties of CSP LEDs
> Thermal management of CSP LED lighting modules
  - Why is thermal management required for LED systems?
  - Importance of thermal management for LED reliability
  - Thermal path inside the CSP LEDs
  - CSP thermal architecture compared to standard LEDs
  - Thermal resistance of CSP LEDs
  - Maximal junction temperature of CSP LEDs
  - Influence parameters on thermal resistance
  - Thermal resistance in the application
  - Reliability of CSP LEDs compared to traditional LED components
  - Major trends in thermal management
  - Main consequences and opportunities arising from the thermal properties of CSP LEDs
> Electrical management of CSP LED lighting modules
  - Electrical behavior
  - Resistive behavior
  - Binning distribution
  - Multiple LED arrangements
  - LED module operating window
  - LED balancing circuit (electrical behavior)
  - Electrical Static Discharge (ESD) and Electrical Over Stress (EOS)
  - Electrical Static Discharge (ESD) protection in LED package
  - Electrical Static Discharge (ESD) protection in LED global system
  - Electrical management - Minimal spacing
  - Main consequences and opportunities of the electrical properties of CSP LEDs
> Precautions for CSP LED integration into modules
  - Handling precautions
  - PCB design for optimal performance
  - Solder recommendations
  - Relflow process for CSP LEDs
> CSP LED lighting module performance in applications
  - Is a CSP a cost effective high power LED or a super mid power LED?
  - CSP LEDs in lighting products - Positioning
  - CSP LED vs COB LED
  - CSP LEDs in lighting products - Opportunities
  - Opportunities for accent lighting
  - Cost value for accent lighting
  - Opportunities for spot light integration
  - Opportunities for general indoor application (i.e.: general lighting)
  - Integration in general lighting applications - Pros and cons
  - Integration in general lighting applications - Case studies
  - Spectrum control with CSP LEDs
  - CSP LED diversity
  - The different types of LED modules - Positioning
  - CSP LED module positioning vs other technologies
  - Market trends - Share of CSP LED module revenue (2016 vs. 2021)

Conclusion 208
Appendix - About Yole Développement 211
Appendix - About PISEO 230

MARKET & TECHNOLOGY REPORT

YOLE DÉVELOPPEMENT

Pars MUKISH holds a master’s degree in materials science and polymers from ITECH and a master’s degree in innovation and technology management from EM Lyon in France. Since 2015, Mukish has taken on responsibility for developing LED, OLED and sapphire activities as Business Unit Manager at Yole Développement. Previously, he worked as Marketing Analyst and Techno-Economic Analyst for several years at the French Research Center, CEA.

Pierrick BOULAY works as Market and Technology Analyst in the fields of LED, OLED and lighting systems, doing technical, economic and marketing analysis at Yole Développement, the “More than Moore” market research and strategy consulting company. He has experience in both LED lighting, including general lighting and automotive lighting, and OLED lighting. In the past, he mostly worked in R&D departments for LED lighting applications. Pierrick holds a master degree in Electronics from ESEO in France.

PISEO

Dr Olivier ANDRIEU is R&D Project Director and Mechatronic and LED System Architect at PISEO. He is working in collaboration with Yole Développement's team to perform comprehensive technical analyses of innovative LED-based optical systems and markets. His expertise is based on the development of disruptive solutions taking into account mechanical, electronic, optic and thermal issues to achieve application requirements. Previously, Dr Andrieu worked for ESI Automotive as head of innovation and more recently for Philips Lighting where he developed and implemented numerous LED lighting solutions on a global level.

Joel THOME is the General Manager and Senior Research and Innovation Consultant at PISEO. In collaboration with Yole Développement’s team, Thome performs numerous technical and market analyses focusing on LED solutions, in addition to developing innovative optical solutions with PISEO’s R&D team. With a master’s degree in mechanical engineering, Thome has worked in the lighting industry for more than 25 years. After beginning his career at Philips Lighting, he has recently held various global business, marketing and R&D senior management positions. During this period he developed strong expertise in lighting controls, LED technology and innovation processes including strategic roadmaps and project portfolio management. Today, Thome is also the administrator of the Gil-Syndicat du Luminaire trade union organisation and the Cluster Lumière association.
ORDER FORM
CSP LED Lighting Modules

BILL TO

Name (Mr/Ms/Dr/Pr):

Job Title:

Company:

Address:

City:

State:

Postal Code/Zip:

Country:

VAT ID Number for EU members:

Tel:

Email:

Date:

PAYMENT

BY CREDIT CARD

- Visa
- Mastercard
- Amex

Name of the Card Holder:

Credit Card Number:

Card Verification Value (3 digits except Amex: 4 digits):

Expiration date:

BY BANK TRANSFER

BANK INFO: HSBC, 1 place de la Bourse, F-69002 Lyon, France,
Bank code: 30056, Branch code: 00170
Account No: 0170 200 1565 87,
SWIFT or BIC code: CCFRFRPP,
IBAN: FR76 3005 6001 7001 7020 0156 587

RETURN ORDER BY

- FAX: +33 (0)4 72 83 01 83
- MAIL: YOLE DÉVELOPPEMENT, Le Quartz, 75 Cours Emile Zola, 69100 Villeurbanne/Lyon - France

SALES CONTACTS

- North America - Steve Laferriere: +1 310 600 8267
  laferriere@yole.fr
- Europe & RoW - Lizzie Levenez: + 49 15 123 544 182
  levenez@yole.fr
- Japan & Rest of Asia - Takashi Onozawa: +81 3 6869 6970
  onozawa@yole.fr
- Greater China - Mavis Wang: +886 979 336 809
  wang@yole.fr
- Specific inquiries: +33 472 830 180 – info@yole.fr

About Yole Développement

Founded in 1998, Yole Développement has grown to become a group of companies providing marketing, technology and strategy consulting, media and corporate finance services. With a strong focus on emerging applications using silicon and/or micro manufacturing, the Yole Développement group has expanded to include more than 50 collaborators worldwide covering MEMS, Compound Semiconductors, LED Displays, Image Sensors, Optoelectronics, Microfluidics & Medical, Advanced Packaging, Manufacturing, Nanomaterials, Power Electronics and Batteries & Energy Management.

The “More than Moore” company Yole and its partners System Plus Consulting, Blumorpho, KnowMade and PISEO support industrial companies, investors and R&D organizations worldwide to help them understand markets and follow technology trends to develop their business.

CONTACTS

For more information about:
- Consulting Services: Jean-Christophe Eloy (eloy@yole.fr)
- Financial Services: Jean-Christophe Eloy (eloy@yole.fr)
- Report Business: Fayçal Khannass (khamass@yole.fr)
- Press relations: Sandrine Leroy (leroy@yole.fr)

About PISEO

A unique innovation platform dedicated to smart LED based optical systems. PISEO owns high skilled engineers and cutting edge characterization equipment, all situated in a single location. The team, mainly issued from an industrial global leader, delivers a whole set of services to the industry throughout the entire product life cycle. Therefore, PISEO runs projects from applied research up to product recycling, including market analysis, technology scouting, strategic planning and industrial design.

CONTACTS

More info on www.piseo.fr
Press contact: Joel Thomé, PISEO General Manager (thome.joel@piseo.fr)
1. SCOPE

1.1 The Contracting Parties undertake to observe the following general conditions as agreed by the Buyer and the Seller. Any ADDITIONAL, DIFFERENT, OR CONFLICTING TERMS AND CONDITIONS IN ANY OTHER DOCUMENTS ISSUED BY THE BUYER AT ANY TIME ARE HEREBY OBJECTED TO BY THE SELLER, SHALL BE WHOLLY INAPPLICABLE TO ANY SALES MADE HEREBY AND SHALL NOT BE BINDING IN ANY WAY ON THE SELLER.

1.2 The Seller shall only be liable for (i) direct and (ii) foreseeable damages resulting from the performance of its obligations under these conditions of sale when signing the purchase order which mentions “I hereby accept Yole’s Terms and Conditions of Sale”.

1.3 Orders are deemed to be accepted only upon written acceptance and confirmation by the Seller, within [7] days from the moment they are registered either by email or to the Buyer’s address. In the absence of any confirmation in writing, orders shall be deemed to have been accepted.

2. MAILING OF THE PRODUCTS

2.1 Products shall be delivered to the Buyer: within [10] months from the order for Products already released; or within a reasonable time for Products ordered prior to their effective release. In this case, the Seller shall use its best endeavours to inform the Buyer of an indicative release date and the evolution of the work in progress.

2.2 Software products shall be delivered via email. The Seller can propose a pre-release discount to the Buyer. The Seller shall by no means be responsible for any delay in release of article 2.2 above, and including incauses where a new event or access to new contradictory information would require for the analyst extra time to compute or compare the data in order to enable the Seller to deliver a high quality Product.

2.3 The mailing of the Product will occur only upon payment by the Buyer. In accordance with the conditions contained in article 3.

2.4 The mailing is operated through electronic means either by email for download or by other electronic channel in the scope of the Business-to-Business (B2B) market. In any case, the Product will be delivered via email/password. If the Product’s electronic delivery format is defective, the Seller undertakes to replace it at no charge to the Buyer provided that it is informed of the defective functioning within [90] days from the date of the original download or receipt of the Product. 2.5 The person receiving the Products on behalf of the Buyer shall immediately verify the quality of the Products and their conformity to the order. Any claim for apparent defects or faults shall be made in writing by the Buyer within [8] days of receipt of the Products. For this purpose, the Buyer agrees to produce sufficient evidence of such defects.

2.6 No refund of the full license price shall be required under article 2.5 shall remain at the Buyer’s risk.

3. PRICE, INVOICING AND PAYMENT

3.1 Prices are given in the orders corresponding to each Product sold on a unit basis or corresponding to annual subscriptions. They are expressed to be inclusive of all taxes. The price may be reevaluated from time to time. The effective price is deemed to be one applicable at the time of the order.

3.2 Yole may offer a pre release discount for the companies willing to acquire in the future the specific report and agreeing on the fact that the report may be release later than the anticipated release date. In exchange to this uncertainty, the company will get a discount that can vary from 15% to 10%.

3.3 Payments due by the Buyer shall be sent by cheque payable to Yole Développement, credit card or by electronic transfer to the following account:

HSBC, 1 place de la Bourse 69002 Lyon France
Bank code: 30056
Branch code: 00170
Account n°: 0170 200 1545 87
BIC or SWIFT code: CGFCFRPP
IBAN: FR76 3005 6001 7001 7025 158 37

To ensure payment is received, the Buyer agrees to produce sufficient evidence of such defects. .

3.4 Payment is due by the Buyer to the Seller within 30 days from invoice date, except in the case of a particular written agreement. If the Buyer fails to pay within this time and fails to contact the Seller, the latter shall be entitled to invoice interest in arrears based on the annual rate Refi of the «BCE» + 7 points, in accordance with article L. 441-6 of the French Commercial Code. Our publications (report, database, tool...) are delivered only after receipt of the full payment.

3.5 In the event of termination of the contract, or of misconduct, during the contract, the Seller will have the right to invoice the stage in progress, and to take legal action for damages.

4. LIABILITIES

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 choosing the Products and for the use and interpretation he makes of the documents it purchases, of the results he obtains, and of the advice and acts it deduces thereof.

4.2 The Seller shall only be liable for (i) direct and (ii) foreseeable pecuniary damages resulting from the performance of its obligations or arising from a material breach of this agreement.

4.3 In no event shall the Seller be liable for:

a) damages of any kind, including without limitation, incidental or consequential damages (including, but not limited to, damages for loss of profits, business interruption and loss of program or data);

b) for any part of the Software Products or arising from

4.4 All the information contained in the Products has been obtained from sources believed to be reliable. The Seller does not warrant the accuracy, completeness adequacy or reliability of such information, which cannot be guaranteed to be free from errors. Any replacement is excluded for any event as set out in 4.3 above.

4.5 The products that the Seller sells may, upon prior notice to the Buyer from time to time be modified by or substituted with similar Products meeting the needs of the Buyer. This modification does not affect the legal validity of the Seller’s agreement provided that the Seller ensures the substituted Product is similar to the Product initially ordered.

4.6 The Seller will, in the case where, after inspection, it is acknowledged that the Product does not meet the performance and quality criteria or that the Seller is held liable, the Seller undertakes to replace the defective products as far as the supplies allow and without indemnities or compensation of any kind for labor costs, delays, loss of productivity, or for any other loss or damage. The replacement is guaranteed for a maximum of two years starting from the delivery date. Any replacement is excluded for any event as set out in 4.3 above.

4.7 The deadlines that the Seller is asked to state for the mailing of the Products are given for information only and are not guaranteed. The Seller shall not be held liable for any damages or cancellations of the orders, except for non acceptable delays exceeding [4] months from the stated deadline, without information from the Seller. In such case only, the Seller shall be entitled to ask for a reimbursement of its first down payment to the exclusion of any further damages.

4.8 The Seller does not make any warranties, express or implied, including, without limitation, those of sale ability and fitness for a particular purpose, with respect to the Products. Although the Seller shall take all reasonable precautions to avoid the transmission of viruses, worms, Trojan horses or other codes containing contaminating or destructive properties before mailing the Products, the Seller cannot guarantee that any Product will be free from infection.

5. FORCE MAJEURE

5.1 The Seller shall not be liable for any delay in delivery performance directly or indirectly caused by unforeseen acts of nature, fire, flood, accident, war, government intervention, embargoes, strikes, labor difficulties, equipment failure, late deliveries by suppliers or other liabilities which are beyond the control, and not the fault of the Seller.

6. PROTECTION OF THE SELLER’S IPR

6.1 All the IPR attached to the Products are and remain the property of the Seller. Any attempt by third parties to copy, redistribute, resell or publish the Products, or any part of it to any other party other than employees of its company. The Buyer shall have the right to use the Products solely for its own internal information purposes. In particular, the Buyer shall therefore not use the Product for purposes such as: Information storage and retrieval systems; Recordings and re-transmiters over any network (including and not limited to: satellite network); Use in any timesharing, service bureau, bulletin board or similar arrangement or public display; Purchase any Product or any other online service (including bulletin boards or the Internet); Licensing, leasing, selling, offering for sale or assigning the Product.

6.2 The Buyer shall be solely responsible towards the Seller of all infringements of this obligation, whether this infringement consists from its own acts or from acts of third parties. The Seller has sent the Products and shall personally take care of any related proceedings, and the Buyer shall bear related financial consequences in their entirety.

6.3 The Buyer shall define within its company point of contact for the needs of the contact. This person will be the recipient of each new report in PDF format. This person shall also be responsible for respecting every condition of sale imposed by the Seller. The Products are not disseminated out of the company.

6.4 In the context of annual subscriptions, the person of contact shall be defined as the person who will be the authorized recipient on line on the reports on I-micronews.com. In this respect, the Seller will give the Buyer a maximum of 10 passwords, unless the multiple sites organization of the Buyer requires more passwords. The Seller reserves the right to check from time to time the correct use of this password.

6.5 In the context of a multiple license, the only the employee of the buyer can access the report or the employee of the companies in which the buyer have 100% shares. As a matter of fact, the investor company of a company, the joint venture done with a third party etc...cannot access the report and should pay a full license price.

7. TERMINATION

7.1 If the Buyer cancels the order in whole or in part or postpones the date of mailing, the Buyer shall indemnify the Seller for the entire costs that have been incurred as at the date of notification by the Buyer of such delay or cancellation. This may also apply for any other direct or indirect consequential consequences to the Seller.

7.2 In the event of breach by one Party under these conditions or the order, the non-breaching Party may send a notification to the other by recorded delivery letter upon which, after a period of thirty (30) days following the sending of the problem, the non-breaching Party shall be entitled to terminate all the pending orders, without being liable for any compensation.

8. MISCELLANEOUS

8.1 All the provisions of these Terms and Conditions are for the benefit of the Seller and the Seller’s current and future parent and agent. Each of them is entitled to assert and enforce those provisions against the Buyer.

8.2 Under these Terms and Conditions shall be given in writing. They shall be effective upon receipt by the other Party. The Seller may, from time to time, update these Terms and Conditions as long as the Buyer agrees to have accepted the latest version of these terms and conditions before proceeding with the business communicated to him in due time.

9. GOVERNMENT LAW AND JURISDICTION

9.1 Any dispute arising out or linked to these Terms and Conditions, or to any application of these Terms and Conditions shall be settled by the French Commercial Courts of Lyon, which shall have exclusive jurisdiction upon such issues.

9.2 French law shall govern the relation between the Buyer and the Seller, in accordance with these Terms and Conditions.