# Winning the Jump Ball: Sorting Winners from Losers in LEDs and Power Electronics

Devices that enable energy efficiency, like light-emitting diodes (LEDs) and improved power conversion electronics, are being increasingly recognized as a part of the energy solution. Across the overlapping value chains in these domains a slew of developers are working on innovative materials and system architectures, targeting the primary challenges of cost reduction and manufcaturability. However, this developer set is muddled, with disruptive start-ups and me-too companies in the emerging markets stepping on the toes of litigious multinational corporations. It is also characterized by evolving partnerships and rampant acquisitions to aid vertical integration. In this report, we highlight the key developers of LEDs and power electronics materials, modules, and systems, separating those that present investors, partners, and regulators with immense opportunity from those that represent potential pitfalls.

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# Executive Summary

Devices that enable energy efficiency, like light-emitting diodes (LEDs) and improved power conversion electronics, are being more and more widely recognized as a part of the energy solution. Incumbents and start ups in both industries across the value chain are betting on new materials such as silicon carbide (SiC) and gallium nitride (SiC) to lower costs and improve efficiencies; cost reduction is also driving innovations in fixture design. We note that:

- SiC and GaN are attractive as epitaxy materials in power electronics and as substrate materials in both LEDs and power electronics providing attractive overlapping value chain opportunities to companies in this part of the value chain.
- In power electronics, new device architectures pursued by FINsix and Arctic Sands are breathing in new life as silicon reaches theoretical limits. While the SiC-based device industry continues to be dominated by incumbents such as Cree, Infineon, and ST Microelectronics, the GaN-based device industry includes many more start ups.
- In LEDs, most innovation lies in the choice of substrates. Where Cree is the sole GaN-on-SiC success story, Soraa looks to lead on GaN-on-GaN LEDs. GaN-on-silicon is attracting both incumbents such as Osram Opto Semiconductors and Samsung, as well as start-ups like Bridgelux and Plessey Semiconductors.
- Cost reduction agenda and design simplicity is also driving the emergence of a new value chain stage – networked fixtures that integrate a control element. Leading companies large (Philips) and small (Lutron) are collaborating to integrate the controller IC within the LED fixture itself, enabling an optimization of efficiencies and bill of materials during design.

## Partnership and Investment Opportunities Remain Throughout the LEDs and Power Electronics Value Chain; with Opportunities Likely to Move Fast

To assess key developers of that present investors, partners and regulators with immense opportunity from those that represent potential pitfalls, we graded the companies in the Materials, LEDs, Power Electronics, and Fixtures/Controllers market segments on the Lux Innovation Grid. We found that:

- In Materials, few players dominate the space, although Cree is the clear winner in SiC substrates. GaN substrate and epitaxy approaches have technical promise but lag in business results – these include companies like Ammono, Azzurro, Translucent, and Kyma.
- In Power Electronics, incumbents such as Cree, Infineon, and ST Microelectronics dominate and wager mostly on SiC. Others, such as Transphorm and Efficient Power Conversion, are moving ahead with GaN-based technologies, while others such as Arctic Sands, FINsix, and CogniPower push the limits of silicon performance with solid technical value, but are lacking now on business execution.
- In LEDs, incumbents battle it out for the top spot while high-potentials use a variety of approaches to carve out their own niches. Luminus Devices looks to push limits of sapphire-based LEDs, with Bridgelux set to lead the GaN-on-silicon space. Soraa is the only company adopting bulk GaN substrates that is young, and makes Soraa's technology immature and more expensive.
- In LED Fixtures/Controllers, dominant players such as Cree and Digital Lumens offer incremental improvements on price or performance with attractive payback periods for the end customers. Others, such as Lattice Lighting and Lunera, however, fall short. Lattice Lighting operates in a highly-competitive market, saturated by good-enough and low-cost solutions. Lunera lacks the patent strength, a significant threat to future freedom-to-operate in a crowded and litigious LED domain.

# Landscape

Technology innovations across the value chain in LEDs and power electronics offer opportunities for partnership and investment; we sort winners from losers to avoid black holes.

## Cost, Efficiency Drive New Materials and Technology in LEDs and Power Electronics

Renewable energy generation, like solar photovoltaics and biofuels, and energy storage for the smart grid or electric vehicles have captured much of the attention from "cleantech" partisans and investors. However, devices that enable energy efficiency, like light emitting diodes (LEDs) and improved power conversion electronics, are being more and more widely recognized as a part of the energy solution. Today, LEDs are competing successfully with conventional lighting sources across a variety of applications, and the U.S. Department of Energy (DOE) estimates that in 2010, switching from incumbent lighting solutions to LEDs in general illumination achieved 0.38 terawatt hours (TWh) of electricity savings in the United States.[1] These trends should only accelerate as LED prices fall (see the report "Cheaper, Brighter, Cooler: The Need for Cost Reduction Past the Package"). Similarly, in applications including renewables, electronics and information technology (IT), transportation, and buildings and industrials, there is a opportunity to make power electronics more efficient, achieving savings in electricity consumption (see the report "Beyond Silicon: Plotting GaN and SiC's Path within the $15 Billion Power Electronics Market"). The DOE projects that about 80% of all electric power generated will flow through power electronics by 2030 (up from 30% today) – further making the case more efficient power electronic solutions.[2] There are many signs of innovation in the these energy-saving devices:

- **New substrate and epitaxy materials are making their way into LEDs and power electronics.** Silicon and sapphire are the incumbent materials in power electronics and LEDs respectively. Wide band gap materials such as gallium nitride (GaN) and silicon carbide (SiC) are making inroads as epitaxy materials in power electronics and as substrate materials in both to enable desirable device characteristics. As epitaxy layers in power electronics, they enable faster switching and higher voltage performance. As substrates in LEDs and power electronic devices, they enable superior electron mobility and thermal conductivity. Better thermal conductivity allows heat to be drawn away from the device and greater electron mobility aids in higher lumen per watt (lm/W) output in LEDs and higher switching frequency in power electronics. Substrate players include a host of large and early-stage companies such as Cree, Rohm, Sumitomo Electric, and Mitsubishi Chemical to Ammono, Kyma, and Sixpoint. Epitaxy players include mainly start-ups such as Azzurro, Translucent, Seen, and Novagan, many of who look to target both industries.

- **Higher switching frequency leads to electricity savings and lower costs in power electronics.** As silicon reaches the performance limits in power electronic device applications, several start-ups and incumbents alike are investing in devices based on GaN and SiC – wide band-gap materials that enable faster switching frequency, leading to savings in electricity consumption. Established companies such as Infineon, Rohm, and Cree are leaders in SiC-based power electronics, with start-ups such as Anvil Semiconductors and GeneSiC following their lead. GaN-based power electronics are earlier in development, but could displace SiC and silicon solutions with even higher performance. However, SiC and GaN remain higher cost, and developers will need to bring cost down through approaches like novel substrates (see the report "Price or Performance: Bulk GaN Vies with Silicon for Value in LEDs, Power Electronics, and Laser Diodes").

- **To improve lm/W output and reduce costs LED companies are investing in new materials.** Over the past decade, the swelling efficiency of LEDs has been a major driver of cost reduction: dies now emit 100 lm/W compared to about 50 lm/W only three years ago. Higher efficiency dies lower $/lm (dollar per lumen) and consequently the cost of LED products. The LED industry is rife with material combinations looking to drive further improvement, ranging from GaN-on-SiC commercialized by Cree; to GaN-on-GaN by Soraa. There are also a host of start-ups and incumbents alike including Bridgelux, Lattice Power, Plessey, and Osram Opto Semiconductors that are pursuing GaN-on-silicon based LEDs, which could dramatically shift the cost structure of LEDs by using cheaper substrates and leveraging existing infrastructure.
- **Cost reduction is also driving innovations in fixture design.** With the multipronged emphasis on reducing LED system cost through innovative materials and dies already yielding dramatic results, the cost reduction emphasis is now shifting to the balance of system elements such as controls and other fixture components. Acquisitions by Cree, Philips, and GE coupled with developments from companies like Lunera and Lutron Electronics point to this next key focus for cost reduction. For example, new developments in fixture design like Lunera's truLITE Color Consistency Process can maintain very high uniformity of quality light without noticeable color difference across the entire installation, to create a productive and healthy environment for users, while achieving integration of battery backup into its LED products. Other developers like Digital Lumens achieve up to 90% energy savings through efficient fixture designs coupled with smart control based on occupancy and daylight harvesting and light scheduling and dimming features. Additionally, various developers are targeting wireless fixtures, based on the ZigBee standard, which enable low-invasive installation, reducing a major barrier to entry into the retrofit market.

All of this innovation activity in LEDs and power electronics faces barriers to commercialization, and coordination and partnerships across the value chain will be needed bring the cheaper and more efficient devices they promise to market most. This report will highlight the key developers of these technology families, separating those that present investors, partners, and regulators with immense opportunity from those that represent potential pitfalls.

## New Substrate and Epitaxy Materials Address Both LEDs and Power Electronics Applications

There's significant overlap between LEDs and power electronics in the materials used, both as substrates and for the thin "epitaxy" layers of active material deposited on the substrate to produce "epi-wafers" that are used to make devices. As such, materials advances are poised to impact both areas.

- **New epitaxy flavors look to take on both LEDs and power electronics.** In LEDs, GaN-on-sapphire is the standard solution, while GaN-on-SiC LEDs are being commercialized by Cree. GaN-on-silicon and GaN-on-GaN devices are now also vying for LED market share as an increasing number of epitaxy companies such as Azzurro, Translucent, EpiGaN, Seen, and Novagan have begun to offer these solutions. Meanwhile, in power electronics, where silicon is the incumbent solution, many of these very same companies are offering GaN-on-silicon, GaN-on-SiC, GaN-on-GaN, and SiC-on-SiC epitaxy solutions. Given the relatively early stage of many of these solutions, both incumbents and start-up fabless device manufacturers look to engage with more than one these companies for development partnerships.
- **SiC and GaN are attractive attention as substrate materials, as well.** Over 90% of LEDs today are made using sapphire (aluminum oxide) substrates, from manufacturers such as Rubicon, Monocrystal, Kyocera, and LG Siltron, while most power electronics are based on silicon substrates. While there's been much work on SiC and GaN epi-layers, both materials can also be used as substrates, providing benefits such as superior thermal conductivity and a closer lattice match with the epilayers. SiC substrates are already used in commercially available LEDs and power electronics applications; Cree, II-VI, Nippon Steel, Dow Corning, and Rohm (SiCrystal) are the primary SiC substrates makers. In contrast, most developers of GaN substrates (bulk GaN) are still only in the R&D stage (see the report "Price or Performance: Bulk GaN Vies for Value in LEDs, Power Electronics and Laser Diodes"). They include a host of start-ups such as Ammono, SixPoint, and Kyma to larger companies such as Sumitomo Electric, Furukawa, and Mitsubishi Chemical.

- **Many tools and processes are largely common to both industries.** Just like substrates and epi wafers, the equipment and growth processes are largely common to both the LEDs and the power electronics industries. Substrate manufacturers for example use the same equipment (for each type of substrate) to manufacture substrates to supply to both industries. Similarly, epitaxy manufacturers tend to use the standard metal organic chemical vapor deposition (MOCVD) process to grow epitaxy layers over substrates. As a result, equipment players, just like materials players, are well positioned to cater to the growing need for new materials technologies in both LEDs and power electronics industries.

## Innovation in Power Electronics is Attracting Both Incumbents and Start-ups Alike

Silicon-based power electronic devices account for nearly 99% of the market in 2012, but silicon devices are reaching their theoretical limits, and wide band gap semiconductors – most notably SiC and GaN – are steadily making inroads into power electronics alongside advanced in device architectures and structures. These new materials offer the promise of better performing devices, as well as superior thermal management – especially critical for temperature sensitive applications such as automotive and industrial motor control and for enabling high-voltage grid applications. These emerging materials still have higher costs than silicon, but their performance advantages and the energy savings they can bring make them the linchpin for innovation in emerging power electronics. In power electronics innovation:

- **New device architectures are breathing in new life as silicon reaches theoretical limits.** A slew of start-ups are taking a different approach to power electronics architectures and circuit designs, ranging from microinverter developers like Array Power and Enphase to more disruptive innovators like FINsix and Arctic Sand. These developers may still use traditional silicon materials, but use radically different designs to achieve high performance, compact form factors, and lower or equal cost to incumbent designs. FINsix is redesigning silicon-based power supplies with an integrated very high frequency (VHF) switching architecture that allows dramatically more compact size. Meanwhile, Artic Sand is targeting DC-DC converters, designing circuits that rely more heavily on capacitors than inductors to minimize passive component needs. While SiC and GaN are beginning to temper the growth of silicon, these radical redesigns could help extend silicon's life and preserve market share.
- **SiC-based device industry continues to be dominated by incumbents...** SiC-based discrete devices will reach $2.1 billion in sales in 2020 (see the report "Beyond Silicon: Plotting GaN and SiC's Path Within the $15 Billion Power Electronics Market"). Compared to GaN, SiC has had a headstart with several current leaders, including Cree, Infineon, ST Microelectronics, IXYS, and Microsemi introducing Schottky diodes, while Cree has already introduced MOSFETs over the past decade. Because of its superior thermal conductivity, wide band gap, and availability of native substrates (same substrate material as the epitaxy layer), SiC-based devices are of special interest in automotive, rail traction, inverters for renewables and for transmission and distribution applications on the grid.
- **…leaving most GaN-based work to start-ups.** GaN-based discrete devices are mostly still in the lab today, but will reach $1.2 billion in 2020 (see the report "Beyond Silicon: Plotting GaN and SiC's Path Within the $15 Billion Power Electronics Market"). The biggest attractions for GaN in power electronics are improved device characteristics over silicon – including higher switching frequency and superior thermal conductivity – while having the potential to be much cheaper than SiC devices. Start-ups Transphorm and GaN Systems are looking to commercialize GaN-on-SiC-based transistors for use in power supplies, PV inverters, and motor drive areas; and start-up Efficient Power Conversion is developing GaN-on-silicon-based devices, as is International Rectifier, one of the few large firms active in GaN devices. The lack of native substrates for GaN has left it behind SiC in commercialization; firms such as Ammono and SixPoint are working on bulk GaN substrates; all are still in pilot production or earlier stage.

## In LEDs, Most Innovation Lies in Choice of Substrates

The incumbent technology for LEDs today is GaN-on-sapphire. While the average efficiency of LEDs made using this material combination is expected to reach 140 lm/W in the next three years to four years, efficiency improvement beyond this level is questionable, given the lattice mismatch between the GaN epitaxy layer and the sapphire substrate. As a result, substrate materials such as SiC and GaN are coming into play, as SiC substrates offer significantly less lattice mismatch and

GaN substrates, of course, have perfect lattice match. That said:

- **GaN-on-sapphire isn't going away just yet.** GaN-on-sapphire LEDs have an average performance of 100 lm/W today, with a few closer to 120 lm/W, and are used by all incumbent LED die manufacturers. These companies continue to push the performance higher using GaN-on-sapphire LED solutions through superior process control, while also moving to larger diameters of wafers in order to bring costs down. Others are pushing the limits of the GaN-on-sapphire technology by designing big-chip LEDs – for instance, Luminus Devices manufactures dies ranging in size between 1.6 $mm^2$ and 9 $mm^2$ (in contrast to a standard 1 $mm^2$ die), providing an output of 1,000 lm to 2,700 lm. Big-chip LEDs can simplify the balance of systems – the drivers, thermal management, and optics required to run the device – breathing life into sapphire-based LEDs.
- **Cree is the sole GaN-on-SiC success story, while Soraa looks to lead on GaN substrates.** Among the top 10 LED companies, Cree is the only firm that develops and manufactures GaN-on-SiC LEDs – which offer industry-leading lm/W output. In May 2012, Cree reported R&D results reaching single-die efficiency of 254 lm/W – more than twice that of GaN-on-sapphire LEDs today – a clear indication of the technology potential and an intimidating roadmap for competing solutions. On the other hand, Soraa is an early-stage start-up, developing GaN-on-GaN LED dies with violet pumped triphosphor for high brightness and high light quality specifically for MR16 lamps. While it hasn't released output numbers, two-inch GaN substrates cost nearly 80 times silicon substrates today, but offer the potential to match or exceed GaN-on-SiC -based LEDs in terms of lm/W output (see the report "Price or Performance: Bulk GaN Vies with Silicon for Value in LEDs, Power Electronics, and Laser Diodes").
- **GaN-on-silicon is attracting both incumbents and start-ups alike.** Where GaN-on-bulk GaN and GaN-on-SiC strives for performance, GaN-on-silicon promises low cost due to the cheap and ready availability of large silicon substrates and silicon-based processing equipment. This prospect has lured both incumbents that are established in GaN-on-sapphire, including Osram Opto Semiconductors and Samsung, as well as start-ups like Bridgelux and Plessey Semiconductors. Despite the collective efforts of these companies, most are still a few years away from mass production. A move to silicon substrates is likely ultimately inevitable, given its cost advantages, but as innovation in incumbent sapphire continues, it's not yet clear if players scaling silicon now will be poised to grab market share when they launch.

## LED Fixtures and Controllers are Capturing Increasing Developer and Investor Mindshare

The race to drive down LED costs has focused on materials and chip/module design to achieve dramatic drop in LED system pricing over the past few years. However, now innovations in fixture and controller design are in a position to paying significant dividends. Specifically:

- **Various fixture designs allow LEDs to better penetrate specific end markets.** A major difference between LEDs and incandescent or fluorescent bulbs is their ability to produce directional light, as opposed to emitting light (and heat) in all directions, using both light and energy more efficiently. However, to capture this benefit as well as LED's generally efficient lm/W performance in systems that consumers are familiar with and can adopt more instinctively requires clever fixture design. Several companies have focused on this aspect of the LED adoption challenge to produce fixtures that come in hundreds of decorative styles, including portable fixtures – such as table, desk, and floor lamps – and hard-wired options such as front porch, dining room, kitchen ceiling and under-cabinet, hallway ceiling and wall, and bathroom vanity fixtures.[3] In the U.S., such fixture manufacturers can seek the Energy Star accreditation, and need to demonstrate a luminaire efficacy k 29 lm/W for directional luminaires, a source efficacy k 65 lm/W (70 lm/W after September 2013) for non-directional luminaires, and a CRI at or above 80.[4] The list of qualified suppliers includes companies like Philips' Color Kinetics, Yellow Energy's Biltmore Lighting, Xing Nan Lighting, Osram Sylvania, and Lightlolier's Lytecaster.
- **Smart controllers enable integration with building energy management systems (BEMS).** Companies like Traxon Technologies offer products that incorporate remote management and custom programming that uses temperature and performance data provided by each fixture to control each individual LED, to allow the

BEMS to control the lighting at the individual LED level based on the desired usage/demand profile. Others have developed offerings like Redwood Systems' Open Application Framework, which allows customers or third parties to access the data acquired by its sensors and use it for other smart-building management applications. For example, data provided by occupancy sensors can help to save HVAC cost when certain rooms are without occupants. Still others, like Adura Technologies, offer wireless mesh controllers that use voltage, current, sensor data (occupancy, lighting level, motion), and other data, adding up to terabytes to wirelessly control lighting using ZigBee, Wi-Fi, or Lowpan wireless protocols via the Internet, SCADA systems, or remote controls.

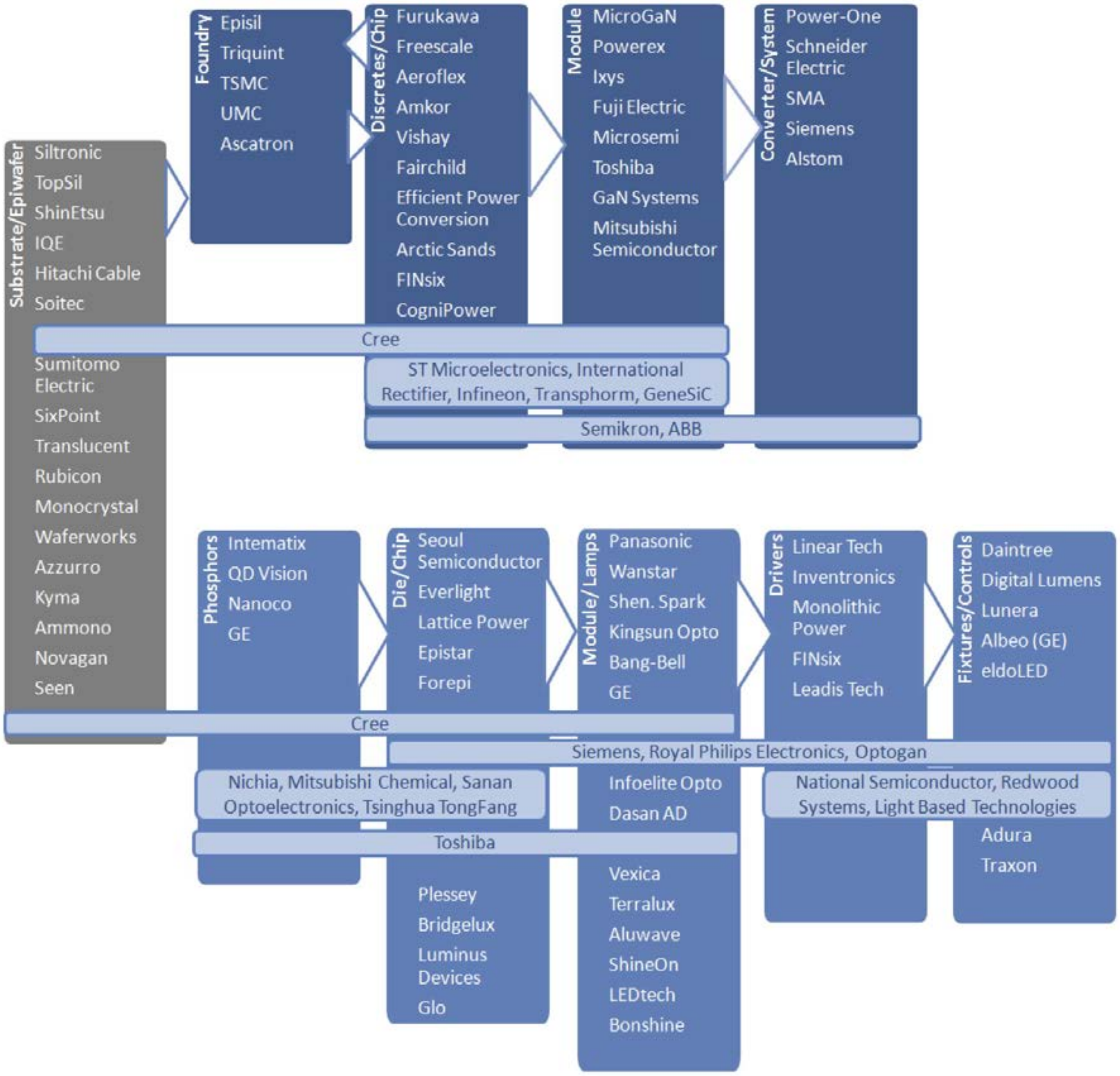
- **Integration of controllers into the fixtures opens up a wholly new efficiency potential.** While fixtures and controllers developers are separately working on optimizing their systems for maximum efficiency, lower costs, and greater occupant comfort, certain leading-edge companies are also collaborating to integrate the controller IC within the LED fixture itself, instead of having it be an add-on like the systems from developers like Redwood Systems and Adura Technologies. Such an integrated design allows for optimization of efficiencies and bill of materials during design, simplifying manufacturing and reducing installation-related disruptions. Although such developments are still at the pilot stage, companies large (Philips) and small (Lutron) are actively pursuing these innovations.

## Partnership Opportunities Lie Across Power Electronics and LED Value Chains

As different as the end applications are for both LEDs and power electronics, both industries share a common value chain for materials and equipment (see Figure 1). Companies looking for partnerships in these industries need to understand the value chain structure and the opportunities and risks at each stage. Surveying the value chain, we find that:

- **Substrate and epitaxy players may LEDs, power electronics, or both.** Bulk GaN substrate manufacturers – from start-ups such as Ammono and SixPoint to larger companies including Mitsubishi Chemical and Sumitomo Electric – are focused on developing substrates for both LED and power electronic applications. In contrast, pure play SiC substrate manufacturers including II-VI, Nippon Steel, and Norstel are largely focused on power electronics applications; vertically integrated manufacturer Cree is the only one with business predominantly in LEDs. The epitaxy processes used to produce device-ready epi-wafers are the same for both industries. Epitaxy specialists from established medium-sized firms like Azzurro and Translucent to other more early stage start-ups such as Seen Semiconductors and Novagan, largely look to cater to both industries – though some narrow their aim, like EpiGaN, which is focused on power electronics applications.
- **Emerging power electronics device makers pursue fast-growing niche segments.** Integrated incumbents such as Infineon, ST Microelectronics, International Rectifier, and Semikron dominate the power electronics market, usually buying silicon wafers and building the epitaxy layer, making discrete devices (such as MOSFETs, Schottky diodes, and IGBTs) and modules. New entrants such as Arctic Sands, FINsix, GaN Systems, and Efficient Power Conversion typically outsource manufacturing to third-party foundries instead of building in-house capacity – though some, like Transphorm, have their own foundries. Arctic Sands, FINsix, GaN Systems, Transphorm, Anvil Semiconductors, and United Silicon Carbide, are eager to excel in product design and architecture to suit specific end-market applications, even where small. They often work with end-market customers to enable custom module build-out. In contrast, incumbents have traditionally focused on high-volume production, pushing for the best cost-performance ratio in their broad product portfolio. This approach is evolving, however, as companies move up in the value chain and look to invest in new material technologies, as ST Microelectronics and Infineon have done in SiC and International Rectifier has in GaN.
- **Booming LED opportunity and pressure to lower costs is driving innovation and preferences.** LED device makers produce dies, lamps, and/or modules. LED dies are light-emitting semiconductor components that go into LED lamps or modules. LED lamps are replacements to existing incandescent and fluorescent bulbs that are typically designed to fit in to existing bulb sockets. LED modules, on the other hand are an assembly of dies, on a printed circuit board or substrate, with optical elements and additional thermal, mechanical, and electrical interfaces, to provide custom lighting elements Dies are made by incumbents such as Nichia, Seoul Semiconductor, Cree, Epistar, and Philips as well as some start-ups such as Plessey, Lattice Power, Luminus Devices, and Bridgelux. While some manufacturers simply supply dies to lamp and module

**Figure 1: Value Chains for LEDs and Power Electronics Overlap Significantly in the Materials Used**




manufacturers, other are vertically integrated. Cree and Philips are also making their own modules, while GE packages dies into lamps for retrofit bulb applications and into modules for general lighting applications. There are module manufacturers such as Vexica, Aluwave, and ShineOn that source dies package them into LED modules for vehicles, street lights, and other commercial and industrial applications, designing modules for different form factors and light requirements.

- **Component manufacturers seek downstream acquisitions to reduce costs and lock in demand.** At the other end of the value chain, a new stage is being added as players arise that integrate the control element with the fixture, with the target of driving down manufacturing costs. A case in point is commercial-lighting-fixtures start-up Lunera, which is integrating Lutron Electronics' wireless lighting controls into its LED fixtures to eliminate separate installation. The companies expect to price the resulting integrated LED lights competitive to equivalent fluorescent lights with controls. Philips and Cree are also developing similar integrated LEDs. Cost pressures and a desire to control end markets has also driven large component manufacturers down the value chain, through acquisitions in drivers, fixtures, and controllers. For example, Cree acquired two fixture companies, LED Lighting Fixtures in 2008 and Ruud Lighting in 2011, while Philips and GE have acquired Color Kinetics (2007) and Albeo Technologies (2012), respectively.

**Figure 2: Investments in LED Industry have Exceeded $1 Billion in the Past Six Years**

| Company Name | Location | Segment | Money Raised since 2006 (US$ millions) | Key Investors |
|---|---|---|---|---|
| Adura Technologies | San Francisco, CA | Controls | $25 | Claremont Creek Ventures ; VantagePoint Capital Partners |
| Chengdu Ying Taili Tech, Co. | Jiangxi, China | Controls | $14 | Fuho Capital |
| Daintree Networks | Mountain View, CA | Controls | $8 | Lend Lease Ventures Pty Ltd. |
| Digital Lumens | Boston, MA | Controls | $16 | Black Coral Capital ; Flybridge Capital Partners ; Stata Venture Partners, Inc. |
| Ecosense Lighting | New York, NY | Module | $13 | Bain Capital Ventures |
| Encelium Technologies | Teaneck, NJ | Controls | $11 | Siemens Venture Capital GmbH ; Townsend Ventures, LLC |
| Lattice Power | Jiangxi, China | Die/chip | $95 | GSR Ventures Management Co. Ltd. ; Mayfield Fund ; Temasek Capital; International Finance Corporation |
| Lumenergi | Newark, CA | Controls | $26 | Low Carbon Accelerator Ltd (AIM:LCA) ; Low Carbon Investors Ltd. ; Noventi LLC; Braemar Energy Ventures |
| Redwood Systems | Fremont, CA | Controls | $34 | Battery Ventures ; Index Ventures ; Mitsui & Co. Global Investment, Inc. ; U.S. Venture Partners; |
| ShineOn | Beijing, China | Modules | $101 | GSR Ventures Management Co. Ltd. ; IDG Capital Partners ; Mayfield Fund ; Northern Light Venture Capital |
| SunSun Lighting | Jiangsu, China | Lamps | $40 | GSR Ventures Management Co. Ltd. ; Oak Investment Partners |
| Wireless Environment | Cleveland, Ohio | Controls | $0.6 | JumpStart Ventures |
| Wuhan Aqualite Co., Ltd | Hubei, China | Dies/chips | $18 | Undisclosed |
| Bridgelux | Livermore, CA | Dies/modules | $224 | VantagePoint, DCM, El Dorado, Chrysalix, Kaistar Lighting |
| Lighting Science Group | Satellite Beach, FL | Lamps | $140 | Bay Harbour Management L.C.; Kingsbrook Partners; Portman Limited; Riverwood Capital; Zouk Capital LLP |
| Soraa | Fremont, CA | Dies, lamps | $95 | Khosla Ventures |
| Luminus Devices | Billerica, MA | Dies/chips | $192 | CMEA Capital, Paladin Capital Group, Argonaut Private Equity, Braemar Energy Ventures, Stata Venture Partners |
| Intematix | Fremont, CA | Phosphors | $40 | Draper Fisher Jurvetson, Crosslink, Samsung Ventures |
| Nuventix | Austin, TX | Heat sinks | $40 | Rho Ventures, CenterPoint Ventures, InterWest Partners, Advanced Technology Ventures, Braemar Energy Ventures |
| Lemnis Lighting | Barneveld, Netherlands | Lamps | $37 | Undisclosed |
| Terralux | Longmont, CO | Module | $24 | Undisclosed |
| Illumitex | Austin, TX | Lens | $44 | Undisclosed |
| Switch Lighting | San Jose, CA | Lamps | $10 | Shenghui Lighting, VantagePoint |

| Company Name | Location | Segment | Money Raised since 2006 (US$ millions) | Key Investors |
|---|---|---|---|---|
| Glo | Sunnyvale, CA | Dies/chips | $40 | Provider Venture Partners, Hafslund Venture, Agder Energi Venture, Teknoinvest, VantagePoint Venture Partners, Agder Energi Venture AS |

## Device Manufacturers have Lured Majority of Investments in Both Industries

We also examined venture capital (VC) investments in materials and technologies for LEDs and power electronics – we counted 71 transactions since 2006, accounting for $1.4 billion in total funding (see Figure 2 and Figure 3). Looking at this funding across the value chain, we found that:

- **LEDs have attracted $1.2 billion over the past six years.** VC investments in the LED industry across the value chain over the past six shows that nearly $640 million of VC money went in to companies manufacturing LED dies years (see also the report "Building a Green 21st Century: Tracking Venture Investments in Green Buildings to Uncover New Opportunities"). In comparison, lighting controls companies have raised about $136 million over the same time period and module and lamp companies have devoted over $360 million. The remainder of the money has gone into developers of phosphors (Intematix), heat sink solutions for LEDs, and lenses.
- **Soraa, Bridgelux, and Luminus Devices stand out as VC darlings in LEDs.** Of the LED device manufacturers, Soraa, Bridgelux, and Luminus Devices alone have attracted over $500 million of VC money, each representing a different flavor of LED technology. Soraa is the only company in the world developing GaN-on-GaN LEDs, while Bridgelux is developing GaN-on-silicon LEDs, and Luminus Devices, which has raised more than $130 million in the last six years, manufactures big-chip LEDs using incumbent GaN-on-sapphire.
- **Drive towards integrated and networked LED lighting garners significant investor interest.** The networked lighting ecosystem includes companies offering solutions that combine ballasts, controllers, sensors and switches, and software. A prime example is California-based Lumenergi, which has raised $26.4 million from investors including Braemar Energy Ventures and Noventi Ventures. Integrated fixtures developer Lunera works with partners like Lutron in light switches, IOTA in battery backup, as well as Adura, Daintree Networks, and Redwood Systems in lighting controls to enabled networked LED lighting – and all these firms have been at the top of the venture capitalists' agenda. Lunera itself has raised at least three rounds of funds totaling about $20 million, with key investors such as Westly Group, Kohlberg Ventures, Navitas Capital, and RCG Ventures.
- **Device manufacturers in power electronics have attracted over $188 million in six years.** VC activity in emerging power electronics has been ramping up, as well, with over $188 million invested in the last six years in developers of GaN-based and SiC-based power electronic devices, with most of the funding pouring in since 2008 (see Figure 3). One of the earliest to raise money included SiC device manufacturer TranSiC in 2006, which was acquired by Fairchild in 2011.
- **Transphorm stands out as a VC favorite in power electronics.** Of all the power electronics makers, Transphorm is the investment darling having raised over $100 million since its founding in 2007, most recently closing a $35 million Series E round of funding in October 2012 led by Innovation Network Corporation of Japan and Nihoh Inter Electronics Corporation. Arctic Sand and FINsix are relying on differentiated circuit design in silicon to compete with GaN-based and SiC-based technology solutions, and have raised $14.8 million so far. SiC device manufacturer SemiSouth had raised $60 million from VCs, but was one of the first casualties of this industry, shutting down its operations in October 2012.

With technology innovations ramping up and investments in the LEDs and power electronics industry growing, it is important to understand that company positions will change over time and strategic decision-makers need to properly interpret opportunities to make educated moves. The Analysis section will sort winners from losers in the LEDs and

**Figure 3: Investments in Power Electronics are Small Compared to the LED Industry**

| Company Name | Location | Segment | Money Raised since 2006 (US$ millions) | Key Investors |
|---|---|---|---|---|
| Arctic Sand | Cambridge, MA | Device | $9.1 | Undisclosed |
| Transphorm | Goleta, CA | Device/module | $106 | Google Ventures, Kleiner Perkins Caufield Byers, Foundation Capital, Lux Capital, Innovation Network Corp. of Japan |
| GaN Systems | Ottawa, Canada | Device | $3.1 | Chrysalix Energy Venture Capital, Rockport Capital |
| SemiSouth Laboratories | Starkville, MS | Device | $60 | Delta Capital, Southern Appalachian Fund, Starkville Technology Investors, Schneider Electric Ventures, Mississippi Angel Fund, Aster Capital Partners, GulfSouth Capital, Power Integrations |
| TranSiC | Kista, Sweden | Device | $4.52 | Industrifonden; Midroc New Technology AB; Volvo Group Venture Capital |
| FINsix | Boston, MA | Device | $ 5.74 | Venrock and undisclosed angel investors |

power electronics industries.

## Landscape Conclusions

- From our review of the LEDs and power electronics landscape, we conclude that:
- Substrate and epitaxy manufacturers are looking ride the growth wave in both the LEDs and power electronics industry.
- Cree is the sole success story in GaN-on-SiC LEDs, as Soraa looks to lead in GaN-on-GaN LEDs; most others companies are pursuing GaN-on-silicon LEDs or new device architectures using GaN-on-sapphire.
- In emerging power electronics, SiC companies have a clear lead on those pursuing GaN-based device solutions; as other start-ups choose to innovate with new silicon-based circuit architectures.
- Cost reduction agenda and design simplicity is also driving the emergence of a new value chain stage – networked fixtures that integrate a control element.
- Booming LED market and a growing power electronics market opportunity are luring VC investments and generating acquisitions.