Catapulse Report Series

SPACE

July 2020

CATAPULT
Compound Semiconductor Applications

ABOUT CSA CATAPULT

Compound Semiconductor Applications (CSA) Catapult is focused on bringing compound semiconductor applications to life in three key areas: the road to Net Zero, future telecoms and intelligent sensing.

CSA Catapult is a Not for Profit organisation headquartered in South Wales. It is focused on three technology areas: Power Electronics, RF & Microwave and Photonics. As well as the three technology areas, CSA Catapult is also working in Advanced Packaging for these high-power innovations.

The next wave of emerging applications will have an enormous impact on our lives. Compound semiconductors will enable a host of new and exciting applications in the electrification of transport, clean energy, defence and security and digital communications markets.

CSA Catapult exists to help the UK compound semiconductor industry grow and collaborates across the UK and internationally.

About Compound Semiconductors

Semiconductors are at the heart of almost all modern electronic devices. Silicon semiconductors have widespread commercial applications, but this technology has its limits.

Compound semiconductors combine two or more elements to create capabilities that cannot be achieved with conventional silicon devices, delivering performance improvements in power, speed and signal quality. This makes them ideal to use in areas such as energy efficiency, electrified and autonomous vehicles, mobile applications, new smart-sensing devices for the Internet of Things and 5G applications.

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Exploring the exosphere

The space race could be argued as the ultimate challenge programme where the brightest minds once competed for space flight superiority in the ’60s that took us to the moon and back. Eventually culminating in collaborative working for the betterment of humanity with the creation of the International Space Station which sits in the exosphere of the planet.

The exosphere is the uppermost region of Earth's atmosphere as it gradually fades into the vacuum of space. At 400km, the International Space Station (ISS) resides at the very tip of this region that traverses the atmosphere and space.

Is sun synchronous the new LEO?

However, beyond the exosphere, a new space race has begun to reach for the skies to provide fast, reliable and reasonably priced broadband to every corner of the Earth where fibre and copper cables cannot reach.

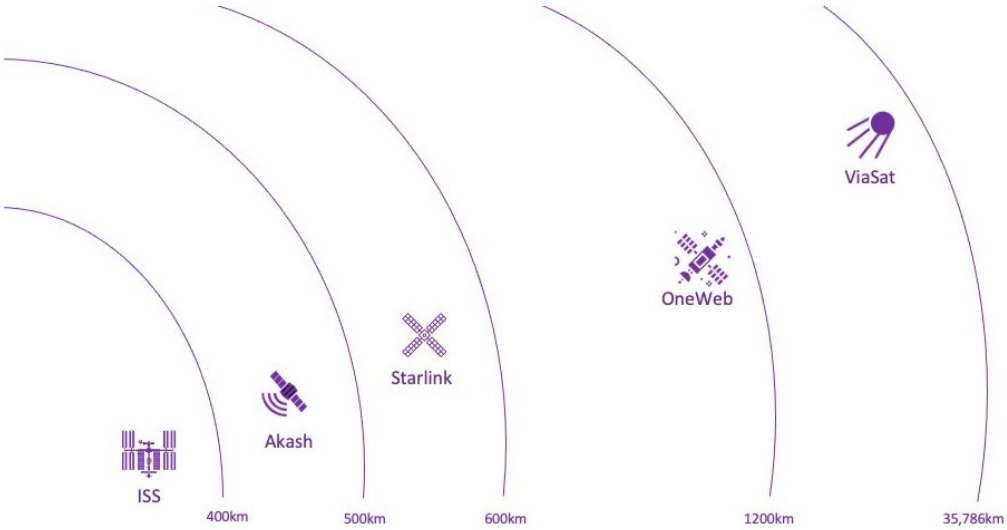


Figure 1: the relative position of the ISS in low earth orbit to the different types of broadband satellites in use

Current satellite broadband solutions range from Viasat which sits high up in a geostationary orbit (35,783km) which has a network of four satellites that can provide up to 100 Mbps broadband but at the cost of $200 a month. HughesNet which runs a similar Geostationary network that currently serves 60% of the rural broadband users in the US but its most

common plans are 25 Mbps at around $50 a month but like talk plans on a mobile phone have an allocated amount of data available to use.

A new generation of satellite constellations is being constructed above us in low earth orbit (LEO) which have been well publicised in recent times. Operating within the 2000km of what constitutes low earth orbit, they promise much faster broadband and low latency (estimated to be <30 ms compared to >300 ms typically for HughesNet) for potentially less money.

Elon Musk's Starlink network is arguably the most famous and has been launching small satellites (up to 60 at a time) via its own rocket company, SpaceX over the last couple of years. It currently has 540 satellites with an operational network of 12,000 planned. They are starting to beta test their system in the US using a 'UFO on a stick' phased array antenna that customers will install on their property.

Source: Reddit

The other satellite network that expects to compete with Starlink is OneWeb. Recently saved from bankruptcy by a £1BN joint venture between the UK government and Bharti Telecom they plan to deploy up to 6,372 satellites, although to date they have launched just 110 satellites and need 648 to become operational.

The appeal for Her Majesty's Government is the centre of operations for OneWeb being based in London and perhaps the opportunity to move satellite production from France and the US

to potentially the UK. While the LEO network doesn't naturally lend itself to GPS solutions, OneWeb does have FCC approval for a medium earth orbit (MEO) constellation which would be suitable for a GNSS type network if they could apply to pivot that application from broadband use. The UK would find this extremely useful as it exits the EU and the Galileo GNSS programme, but would still require a GPS capable satellite network to be built from scratch, which would cost billions.

While OneWeb and Starlink's approach is innovative in its own way, the network that has caught the Catapult's attention is Akash Systems. While they have not announced much about their technology and have yet to launch their first test satellite, their choice of a sun synchronous orbit which is sandwiched between OneWeb and Starlink's orbits is an interesting one.

They estimate this combined with their more efficient technology; they will need fewer satellites to achieve equivalent coverage as their competitors and expect a downlink capability of five gigabits per second. Crucially they are using compound semiconductor technology to achieve this.

Quantity equals quality

Both Starlink and OneWeb plan to use thousands of small satellites that are moving in a rapid low earth orbit. To provide consistent broadband connectivity, the satellites need to be stitched like a patchwork quilt in the sky to work in concert with one another to provide that seamless end-user experience.

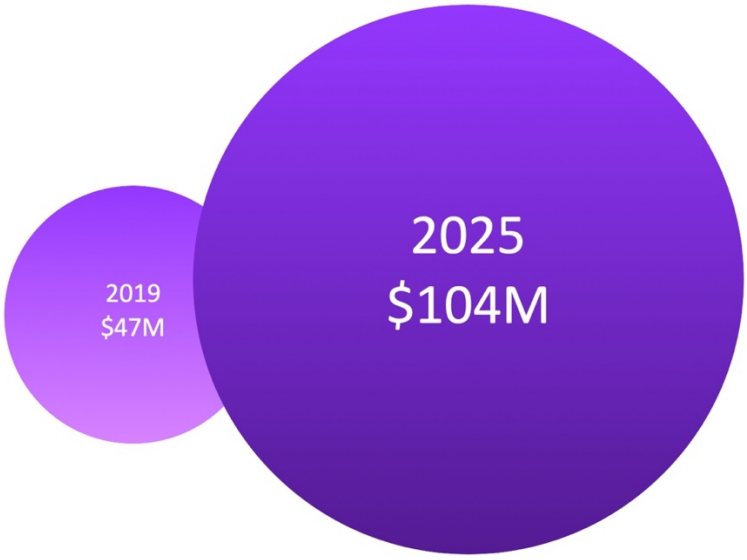
But putting up eventually 40,000 satellites is both time-consuming and costly. Could compound semiconductors be the solution to have fewer satellites in the sky but provide the same performance?

Operator	Satellite type	Technology	Spectrum	Orbit	Size of network
Akash Systems	CubeSat	GaN-on-Diamond	Ka-band	500km	Est <1000
OneWeb	MicroSat	TBC	Ku-band	1,200km	6,372
Starlink	SmallSat	Proprietary	Ka and Ku-band	550km	12,000

Figure 2: Upcoming satellite broadband networks compared

Long term gains of GaN

The satcoms (satellite communications) market is a massive business. Frost & Sullivan estimate by 2026, the global market as a whole, will be worth over $40BN. However, compound semiconductors will play a small role in this with an estimated one or two percent market share (around $104M in 2025) because like other market segments, they are harder to produce at scale and more expensive to manufacture.



Source: Yole Développement

Figure 3: 2019 – 2025 GaN RF device market forecast for satcoms

But while compound semiconductors might be considered niche, this is where Akash may have the advantage over the billion-dollar funded competitors through its innovative use of compound semiconductors, specifically applying a synthetically grown diamond substrate to a Gallium nitride wafer (GaN-on-Diamond).

The benefits of both GaN (Gallium nitride) and GaN-on-Diamond are numerous, but the most prominent property is their excellent thermal conductor capability; as much as 40% reduction in channel temperature for the same power density of GaN-on-SiC. Ideal for the harsh environments of space where temperatures fluctuate to a great extent from less than -100°C to more than 120°C.

Research and development into GaN-on-Diamond has been ongoing for more than two decades with varying degrees of success, and it's no coincidence that the founder of Akash

systems, Felix Ejeckam, was one of those pioneers before he sold the technology on to one of the oldest diamond miners in the world, De Beers through their company Element Six. He argues that the use of GaN-on-Diamond power amplifiers in a satellite constellation could reduce the "dollars per bit" by a factor of a 100.

While the prototype is a CubeSat class device weighing approximately 19g, it is only designed to last six months. The final Akash satellites will be designed to have a service life upwards of five years. But if it is even half the weight of the 260kg Starlink satellites being deployed the cost savings on the per kg performance on the rocket payload could be immense.

Private space

Source: Virgin Galactic

Figure 4: Virgin Galactic will offer suborbital flights in the next decade

Space has long been the obsession for several prominent entrepreneurs such as Richard Branson of Virgin Galactic and the world's richest man, Jeff Bezos, the founder of Amazon through his private rocket company, Blue Origin.

Their current focus is in the sub-orbital (100km) layer with an initial proposition of creating a reusable craft that can host 'space tourism' trips to orbit the Earth then perhaps the moon. Both are at various stages of testing before commercial services can commence.

However, leaping ahead of both these men is Elon Musk's backed SpaceX. Ultimately Musk's goal is to colonise Mars. But in the meantime, his experiments in space technology both through the deployment of Starlink, experimenting with reusable rocket technology and successful unmanned launches of payloads for other companies, the knock-on effect is he has taken the first steps to democratising space travel.

There are several factors why there is such frenetic activity in the hemispheres. Firstly, the fall in costs. Between 1970 and 2000, the cost to launch a kilogram to space remained relatively steady, with an average of $18,500 per kilogram. When the space shuttle was in operation, it could launch a payload of 27,500 kilograms for $1.5BN, or $54,500 per kilogram. For a SpaceX Falcon 9, the cost is just $2,720 per kilogram.

Secondly, rockets are pretty reliable these days too. For every mishap you hear of Space X's returning booster rockets missing the landing platform, there are three successful launches that you never hear about. In fact, Starlink expects to launch every two weeks an unmanned Falcon 9 with 60 satellites on board, unless it is sharing its payload with a customer.

Source: NASA

Figure 5: Crew aboard the SpaceX Dragon reusable rocket

But the most significant step for privatisation of space is manned missions. In June 2020 SpaceX was the first private rocket company to successfully transport NASA astronauts to the ISS from the USA since the space shuttle program ended in 2011. Since the original Demo-2 mission success, the first certified NASA mission, codenamed Crew-1 launched in November 2020 and is midway through a 180-day deployment at the ISS.

Such success has paved the way to potentially private companies being able to send up their astronauts to work on commercial experiments at the ISS. Axiom Space is planning on sending up four astronauts in the second-half of 2021 for a ten-day privately-funded mission at the cost of $55M a seat!

The microgravity environment is of particular interest to people who create materials for miniaturised devices and computers. The more obvious advantages of working in a microgravity environment have been the yield and quality of materials grown. Often crystals grown in experiments to date have been as much as six times larger than back in Earth. And because of the lack of gravity, they are uniform in shape, which means close to zero imperfections; the ultimate goal of epi wafer manufacturing.

The challenge is manufacturing at scale in a microgravity environment. There have been a number of initiatives to 'make things in space', including 3D printing in zero gravity in the ISS. Certain satellites in the 90's had automated manufacturing experiments onboard but benefited from being transported safely by the space shuttle, instead of re-entry through the earth's atmosphere.

Again, the success of manufacturing in space will come down to the cost per kilogram of transporting those raw materials to space and then the ability to return those finished products back to earth. With the success of the reusable Dragon 2 by SpaceX in their most recent mission to the ISS, those costs could be further reduced.

Conclusion

The exosphere is going to get very busy in the next few years. Historically speaking there is a total of 4,987 satellites currently circling the earth at various orbits. Only 2,000 of these are operational. If OneWeb and Starlink have their way that number is expected to increase by a massive 4,000% in the next three to five years!

So, where in the world does the UK fit into all this latest space race? Given the opportunity to introduce innovative technology in this area, CSA Catapult views space as an important market opportunity that is ripe for intervention for encouraging industry to adopt compound semiconductors into forthcoming solutions and devices.

We are already working in partnership with industry and relevant agencies such as the UK Space Agency and will continue to work with ESA (European Space Agency). Crucially the UK's membership of the ESA is not affected by us leaving the European Union as it is not an EU organisation.

Glasgow is already the biggest manufacturer of satellites in Europe. With the investment of half a billion dollars in OneWeb by HM Government, there will no doubt be incentives to develop homegrown satellite solutions to meet the demand of the network build-out plan. The Catapult can potentially help make that happen through industry collaboration and our ability to help build consortiums.

Using the Catapult's MCIV (modelling, characterisation, integration and validation) framework, we can transform a raw concept into a market-ready product, in a process known as virtual product development (VPD).

The VPD capabilities of CSA Catapult have been configured to support the flow of commercial, market-or customer-oriented development projects. So, we can help those involved in the creation of these smaller, lighter, yet equally powerful satellites that networks like OneWeb will need to support their broadband network in the sky.

The Catapult has scientists that have experience in RF, microwave and photonics. So, we can help companies with the implementation of components and system solutions that use up and coming technologies like GaN and GaN-on-Diamond as well as packaging solutions that make the most of thermal properties of compound semiconductors that can survive the rigours of space.

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The CSA Catapult is a member of CS-Connected – the South Wales compound semiconductor cluster

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