Laser-based selective metallisation for large 3D electronics

Create antennas, capacitive touch and frequency selective components on complexly curved surfaces by utilising our printed electronics capability

Introduction

Who are Q5D?

Q5D is a UK based software and robotics company. We use advanced CAD/CAM software along with novel 5 axis robotic machines to automate the deposition of wires and metallisation on large 3D surfaces. In this whitepaper we discuss our laser-based processing capability for surface metallisation.

Additively Manufactured Electronics

Additively Manufactured Electronics (AME) represents a transformative approach to fabricating lightweight, functional components across various industries, including automotive, aerospace, and consumer electronics. By integrating electronic functionality directly into structures, AME not only facilitates weight reduction but also enhances component capability. This is particularly advantageous in applications such as antenna design, where geometric flexibility can optimize performance. Additionally, AME contributes to reducing material waste, shortening production cycles, and streamlining supply chains by minimizing intermediate processing steps. The additively manufactured electronics market is growing rapidly, at 22% year-on-year, and is estimated to be worth $60billion by 2030.

Q5D's Technology

We have been developing our in-house AME capability and now have a unique 5 axis machine with an embedded 100W 1064nm fibre laser, capable of automated, rapid manufacture of precisely metallised 3D shapes. Our machines have a significant working volume of 1x0.5x0.5m so can handle large parts. We work together with customers to make their AME challenges a reality.

Figure 1 - A copper metallised 3D laptop antenna produced by Q5D using a laser-based process, followed by electroless copper plating. The use of 3D shapes in antenna design can improve performance.

Current Technologies in AME

A critical challenge within the industry lies in developing scalable manufacturing technologies capable of producing 3D electronics with a high degree of automation while maintaining substrate agnosticism. Few existing processes support a broad spectrum of substrates, and those that do often require further refinement to achieve commercial viability.

Laser Direct Structuring

Laser Direct Structuring is one of the most commercially advanced methods within AME for forming 3D circuitry. In this technique an expensive, specialist substrate is manufactured which contains nano metal seed layers. When the material is laser processed it enables the metal nano particles to act as catalyst sites for a subsequent electroless plating step. The main limitation for LDS is the constraint on substrate compatibility, as well as proprietary restrictions on material selection. It is also somewhat inefficient given the many different steps required in the manufacture workflow.

Screen printing

More traditional approaches to integrating conductive tracks onto three-dimensional surfaces have frequently relied on screen printing methods, wherein conductive tracks are deposited onto 2D flexible sheets and subsequently affixed to the 3D target geometry. While effective for two-dimensional or simply curved surfaces, this approach is fundamentally inadequate for true 3D structures due to geometric constraints, which hinders design flexibility and electrical performance.

In Mould Electronics

In mould is essentially an extension of screen printing in that the conductive tracks are initially deposited on a flat, flexible substrate, which is then vacuum or thermo-formed onto a solid 3D base. The substrate deforms to the shape of the solid 3D base. This suffers from the similar geometric issues to screen printing in that it cannot easily cope with sharp radius of curvatures or large aspect ratios as this would require the substrate (and so conductive tracks) to stretch too far, thereby limiting performance and function. Additionally, it is very difficult to perfectly predict the deformation, limiting the geometric accuracy of the metallisation shapes. It also suffers from limitations in choice of flexible substrate.

Inkjet/Aerosol jet deposition

Aerosol jet technology involves jetting a conductive nano ink or paste directly onto a substrate. In most cases the desired track resolution is achieved by changing the nozzle aperture size. This is a promising area of AME as it can be utilised for 3D shapes, as long as the system is contained with a 5-axis motion platform. However, the system is rather limited in terms of speed, with the time taken increasing with narrower track deposition. It also generally requires an additional, and often slow, baking process which is mostly performed off machine. This is required to sinter the particles to improve their conductivity.

Q5D’s Technology: CY10-L Machine

Q5D’s approach attempts to blend the best aspects of the technologies above, by combining laser processing with ultrasonic spray deposition of conductive particles. Ultrasonic spray technology is an aerosol-based deposition process which uses a very low deposition force, allowing for more controlled spraying, with minimal overspray, compared to other techniques.

Additionally, to bypass some of the limitations of existing AME processes, our solution for imparting electrical functionality to complex 3D geometries avoids the reliance on intermediary films or specialized substrates.

Our CY10-L laser product achieves fine resolution (≤100 µm), high processing speeds (>2 m/s), and tuneable energy delivery to achieve precise material processing. With appropriate selection of laser source and processing approach, this enables near-universal substrate compatibility. Q5D’s solution leverages 5-axis laser processing, a large working volume (1 × 0.5 × 0.5 m), and a fully digital workflow to facilitate precise metallisation of large-scale 3D structures. By integrating advanced automation and scalable processing capabilities, this technology represents a significant advancement in the commercial feasibility of AME for next-generation electronic applications. The CY10-L also includes a specific 5 axis software package, written in house, and associated support.

Figure 2 Q5Ds CY1000 5-axis platform

Process Overview

The first step is to spray the surface of the part with a silver or copper nano particle solution. Alternatively, a silver paste or mask can be deposited onto the surface. Once a conductive layer/mask has been sprayed or deposited onto the surface, laser processing can be utilized for two distinct functions: 1) material ablation and 2) sintering of conductive particles. Often, a combination of both techniques is employed to create high-resolution conductive traces with optimal electrical performance.

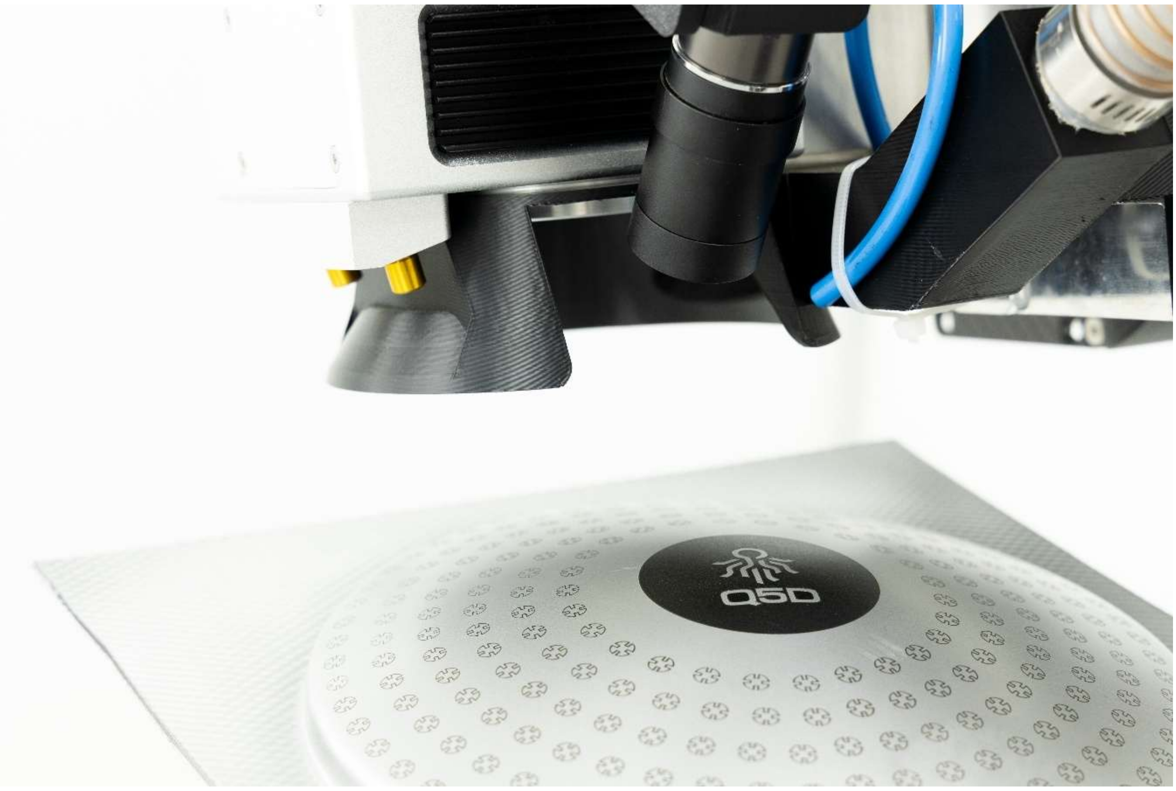


Figure 3 Q5Ds laser head with 100W fibre laser including integrated high-speed mirror galvanometer system and camera monitor

Ablation Process

The conductive coating or mask is rapidly removed using laser ablation to achieve fine-feature track resolution (≥100 μm). In this regime, nanosecond-scale laser pulses are applied to efficiently ablate the conductive material while minimizing thermal diffusion, thereby preventing substrate damage. The resulting conductive tracks can either undergo sintering to enhance their conductivity or serve as seed layers for electroless plating, enabling the formation of high-integrity electrical pathways.

Sintering Process

After ablation the laser is switched to continuous-wave mode to selectively sinter the material. This process heats the embedded metallic particles within the deposited conductive ink, facilitating their fusion into a continuous conductive track while maintaining precise pattern resolution. This technique offers a speed improvement over conventional oven-based sintering.

A key advantage of our technology is the ability to perform the entire process in-house, encompassing coating, ablation, and sintering, within a single workflow. However, a trade-off exists in terms of conductivity: typical conductive inks can achieve up to one-third of the bulk conductivity of silver, whereas electroless plating can reach nearly 100% bulk conductivity. While 30% bulk conductivity is sufficient for most applications, additional chemical plating steps can be incorporated when higher electrical performance is required i.e. the process can be tuned to suit the requirement.

Bringing hardware and software together for automated digital processing

One of the persistent challenges in aerospace and advanced electronics manufacturing is the fabrication of custom radio frequency (RF) patterns on doubly curved 3D surfaces, which cannot be easily achieved using conventional metallized thin films. To demonstrate the 5-axis capability of the CY10-L system, a large radome-style component (200 mm diameter) (figure 4) was designed and fabricated with a laser etched Frequency Selective Surface (FSS) pattern. Our custom in house software optimised the laser machine toolpath required to process the dome. This dome surface could form part of a layup, with the FSS dome in the middle, for example of as part of a radome assembly.

FSS structures consist of periodic radiating elements that function as band-pass or band-stop filters, commonly utilized in radar systems. They have applications spanning consumer electronics, aerospace and automotive industries. While FSS designs are conventionally applied to planar surfaces, direct integration onto complex 3D geometries presents significant manufacturing challenges.

To validate this capability, a hollow dome structure was designed, incorporating an arrayed frequency-selective pattern alongside the Q5D logo. The FSS unit cell is based on a single-band ring loop structure.

The machine path was generated by defining marker locations at each FSS structure position within the CAD model. Our in-house software platform then computed the toolpath required to accurately navigate to these positions within the machine, automatically triggering the appropriate laser pattern at each predefined point.

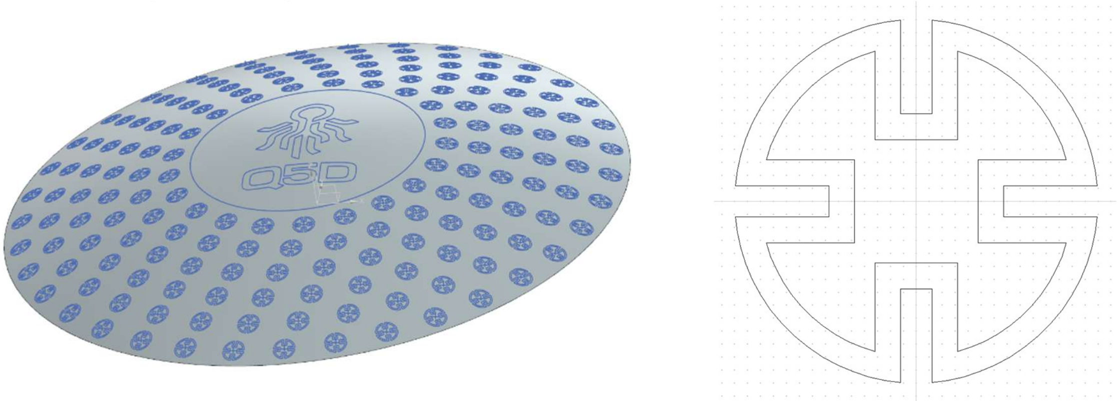
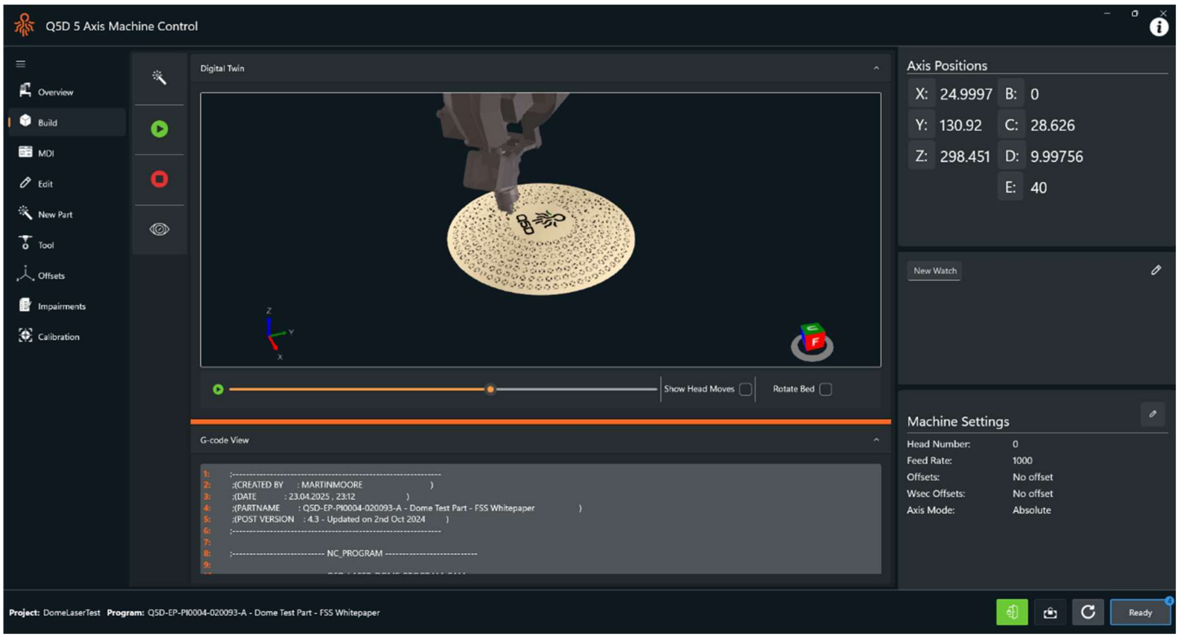


Figure 4 Q5Ds functionalised dome demonstrator with embedded Frequency Selective Structures. The FSS unit cell is shown on the right-hand side

A thick silver-based conductive paste from Dycotek was applied to the dome surface, functioning as the primary conductive layer, which was then subjected to selective laser ablation to expose the desired pattern.

Part alignment was achieved using a jig, configured along the central axis of the rotational bed. In instances where manufacturing tolerances introduce positional deviations; the system is equipped with a 3D scanning capability to accurately determine the part's actual geometry and adjust the machine path accordingly. Such corrections were not required for this specific project.

The laser parameters were optimized to ensure effective removal of conductive paste while preserving the integrity of the underlying substrate. This process involved fine-tuning laser power levels and pulse repetition rates to achieve selective ablation without inducing thermal degradation.



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Y: 130.92 C: 28.626
Z: 298.451 D: 9.99756
E: 40

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Wsec Offsets: No offset
Axis Mode: Absolute

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Figure 5 - Q5D's in house machine control software showing a digital twin of the part and tool

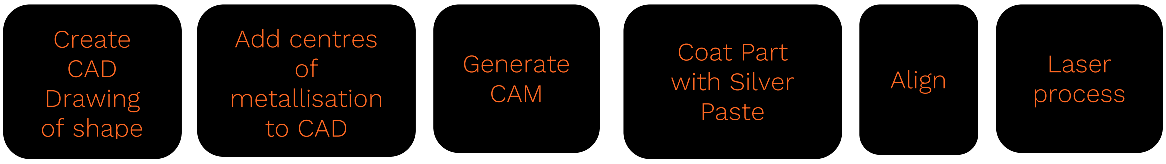

Figure 6 - Workflow for demonstrator part creation


Figure 7 - Q5D Frequency selective demonstrator on doubly curved surface

Summary

Additively manufactured electronics represent a significant advancement in manufacturing, enabling the integration of highly functional and space-efficient electrical components that were previously unattainable with conventional fabrication techniques.

Despite the progress in additive manufacturing, metallising complex geometries remains a challenge for most manufacturers. Q5D's innovative approach addresses this limitation by leveraging a fully digital workflow, along with a rapid laser-based process, to facilitate the metallisation of large 3D components. This process enhances design flexibility, accelerates development cycles, and reduces time to market for new products.

Using our 5-axis machine platform, we have successfully fabricated a metallised doubly curved dome with embedded frequency-selective components. Our methodology incorporates precision laser processing to optimise speed and achieve high-resolution features, ensuring reliable electrical performance. The integration of a digital workflow enables rapid iteration of large-scale custom designs while minimising processing time.

Furthermore, the system allows for tuneable conductivity, adapting the process to specific application requirements. This approach is highly versatile, accommodating a wide range of custom substrates, offering improvement over competing technologies. Whether the objective is to embed capacitive elements, fabricate complex 3D antenna structures, or route electrical tracks around intricate geometries, amongst many other applications, our technology provides a solution for realising advanced electrical designs.

Do you have an AME challenge? Get in touch

Q5D Benefits

- Large size component compatibility
- 3D substrates
- Wide variety of substrates
- Process can be tuned to suit in terms of conductivity and thickness

Comparison table of AME technology process capabilities

Process	Substrate agnostic	High conductivity possible?	Feature resolution	Part Size	Limited geometry?	Process Speed
Laser Direct Structuring	No, requires specialist material	Yes	High	Limited by substrate cost and machine size	Depends on motion platform	High
Screen printing	No – relies on intermediary film	No – usually sintered pastes	High	Large	Only 2D and simple curves	High
In mould	No – relies on vac forming compatibility	No – limited by thermoformable ink selection	Medium	Large	Limited by process	Low
Aerosol/ink jet	Yes, to a large extent	No, limited to 1/3 bulk metal	High	Depends on machine, usually small	Depends on motion platform	Medium, slow for fine features
Q5Ds Process	Yes, to a large extent	Yes, by tuning approach	High (~150um)	Large	No - 5 axis platform	High