IMPALA

PROJECT FINAL REPORT

Grant Agreement Number:	CP-TP 214380-2
Project Acronym:	IMPALA
Project Title:	Intelligent Manufacture from Powder by Advanced Laser Assimilation
Funding Scheme:	NMP Seventh Framework Programme
Date of latest version of Annex I against which the assessment will be made:	27 July 2012
Period covered	1 September 2008 to 31 August 2012
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IMPALA Project Document Reference:	FR-EA-122 – **Figures and Tables Appendix to Project Final Report for SESAM**

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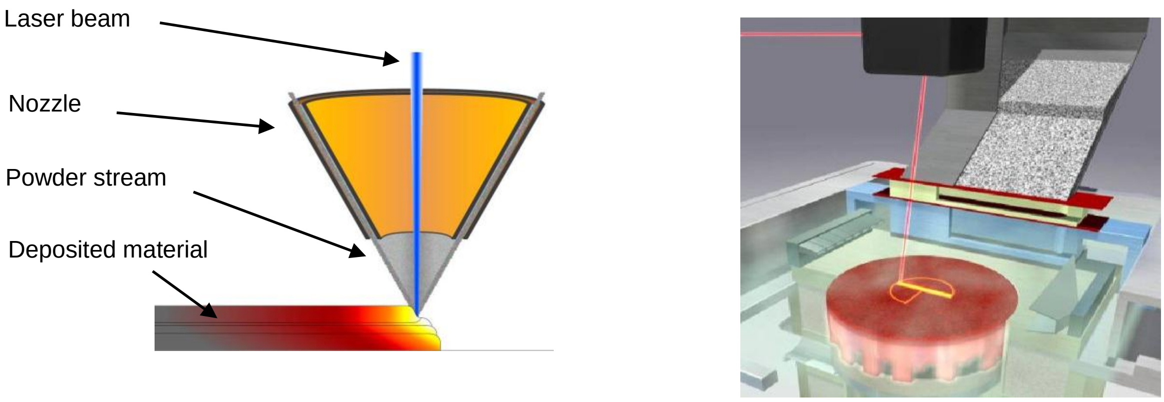


(a) Laser blown powder

(b) Laser powder bed

Figure 1 Schematics of the Laser powder deposition process and Laser powder bed.

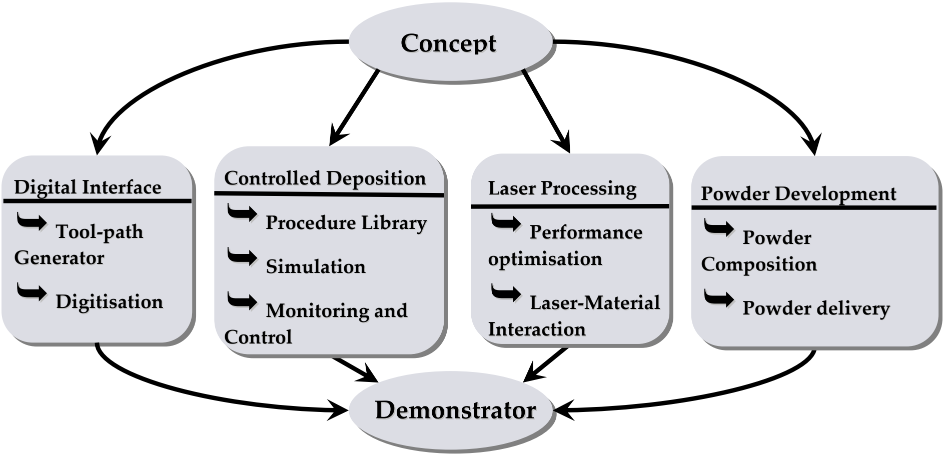


Figure 2 Interaction of technologies developed in IMPALA.

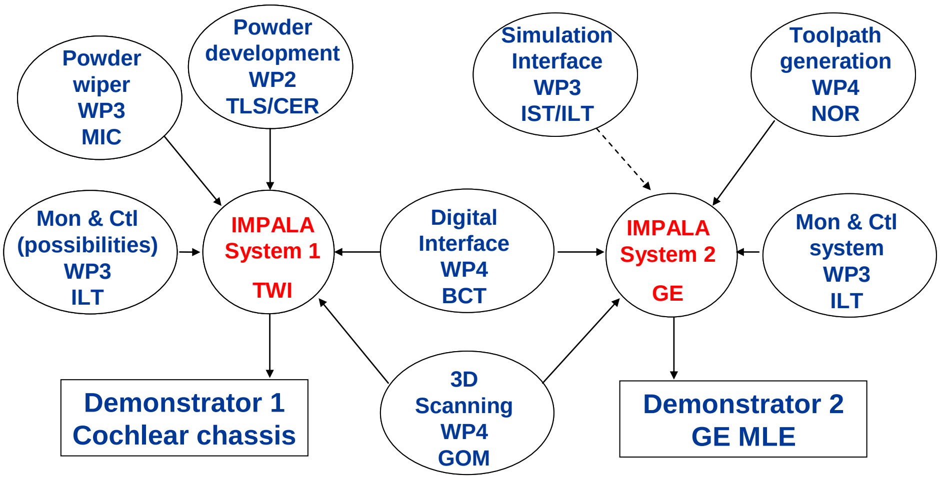
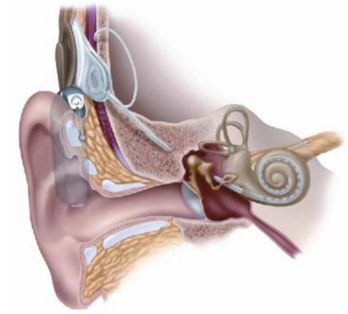


Figure 3 Integration of IMPALA developments into the IMPALA Systems, dotted line denotes activity not to be fully integrated in the system.



- Customisation:
    - Important in development phase
    - Less important in production phase: 80% of volume will be made up of two variants.
- Miniaturisation:
    - Total dimensions 20 x 20 x 20mm
    - Most critical part sin the chassis require tolerances of ± 10µm
- Reduced cycle times
    - Production costs (<60€/part)
    - Volume (30k parts/year)
- Material: Titanium T40
- Other challenges and requirements
    - Reliability is a key parameter
    - Porosity and biocompatibility are main concerns

Figure 4 Chassis implant justification for demonstrator selection.

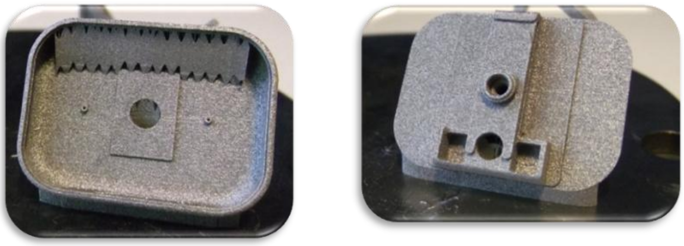
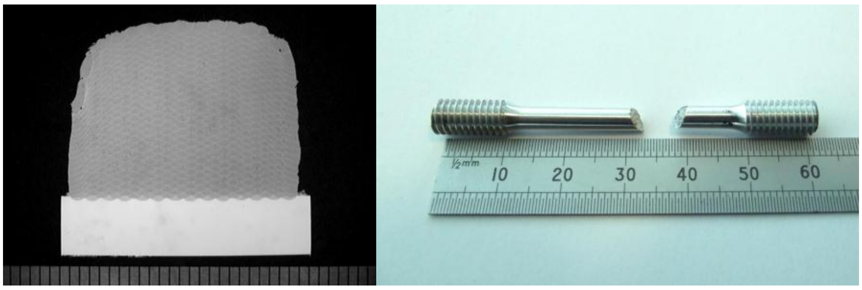


Figure 5 Cochlear chassis case produced using LAMP.

- Customisation:
    - Design flexibility
    - Different sizes – no tooling to produce
- Reduced cycle times
    - Less than or equal to 10 hours
    - Powder capture efficiency – material cost
    - CAD design → final part
- Challenges
    - Near net shape manufacturing
    - Complex 3D geometry – distortion
    - Surface roughness
    - Size – 42" or 47" high

Figure 6 MLE justifications for demonstrator selection and MLE demonstrator produced for the IMPALA project, approximately 46" in height.



a) b)

Figure 8 a) Cross-section micrograph of mechanical test deposit Density approximately 95.6% b) Fracture from tensile test.

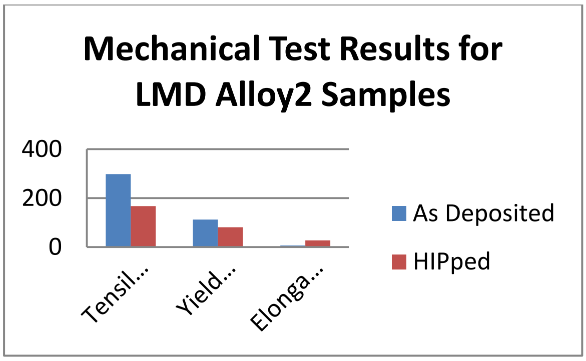


Figure 9 Mechanical test results of Alloy 2 samples in the as deposited and HIPed conditions.

Figure 10 EIGA atomiser.

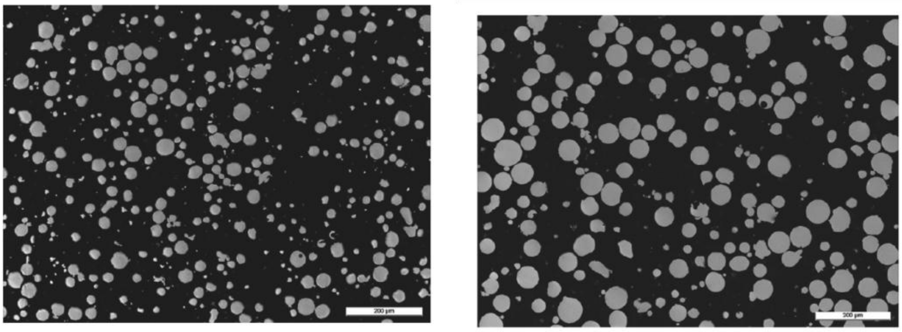


Figure 11 a. Ti6Al4V 25 – 45 µm b. Ti6Al4V 45 – 75 µm

Figure 12 Alumina block produced using laser powder bed technology.

Figure 13 Powder Feeder for powder bed system.

Figure 14 The proposed new powder stirrer for the powder feeder for the powder bed process.

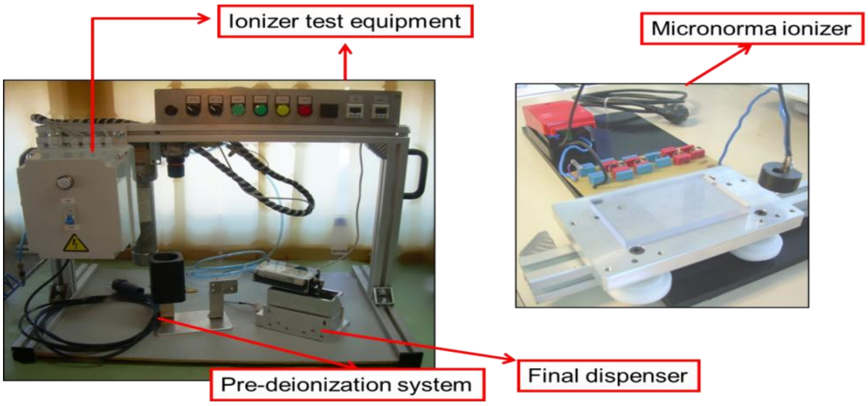


Figure 15 Powder deionization system.

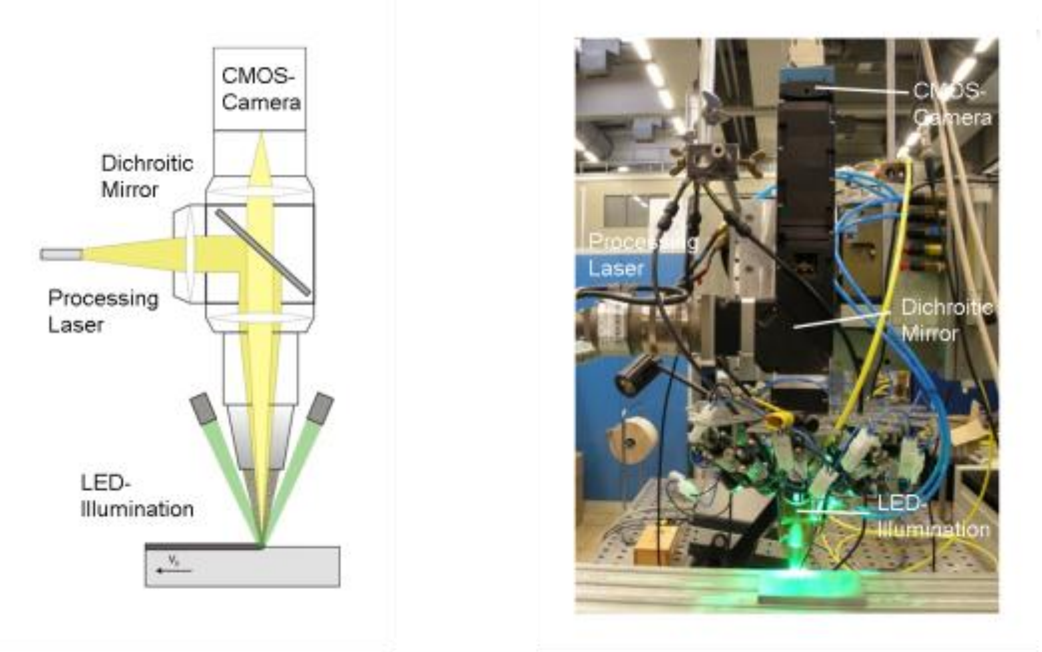


Figure 16 IMPALA MOC system at ILT.

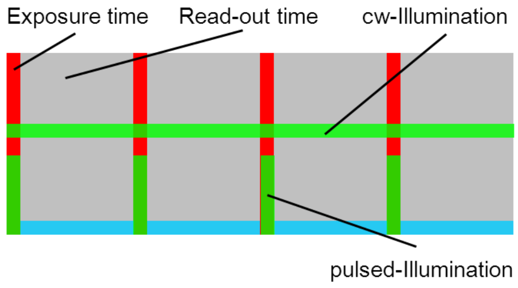
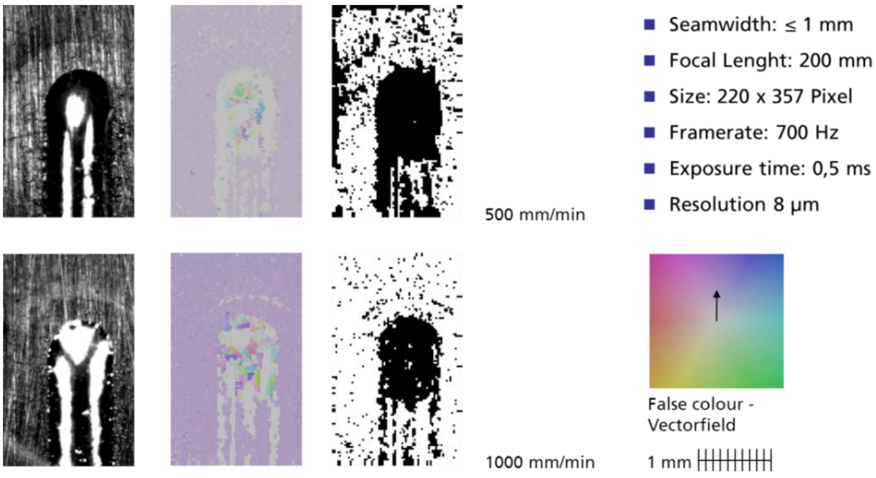
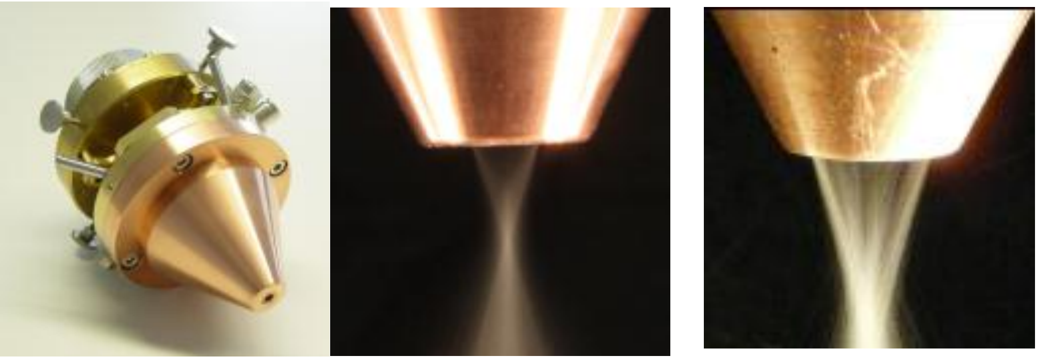


Figure 17 Scheme for LED pulsing and image acquisition.



- Seamwidth: ≤ 1 mm
- Focal Lenght: 200 mm
- Size: 220 x 357 Pixel
- Framerate: 700 Hz
- Exposure time: 0,5 ms
- Resolution 8 µm

Figure 18 Image processing algorithms for velocity analysis.



a) b) c)

Figure 19 Improved nozzle design (a) and powder focus (b) when compared to a convential nozzle (c)

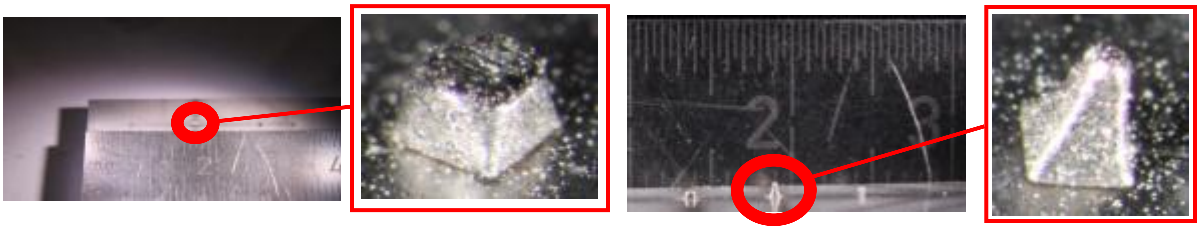


Figure 20 Miniaturisation sample produced at IWS.

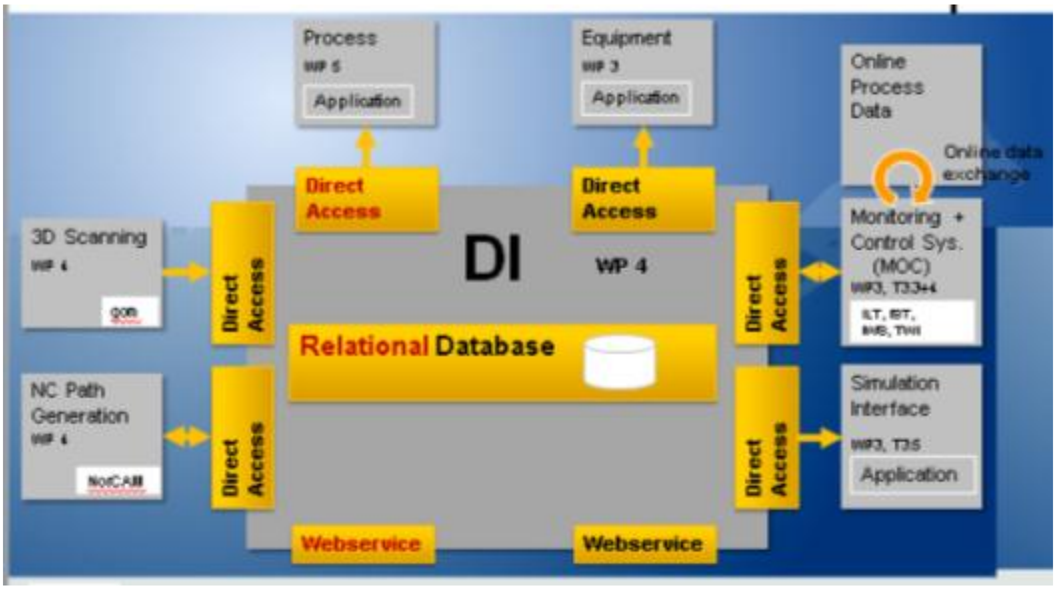
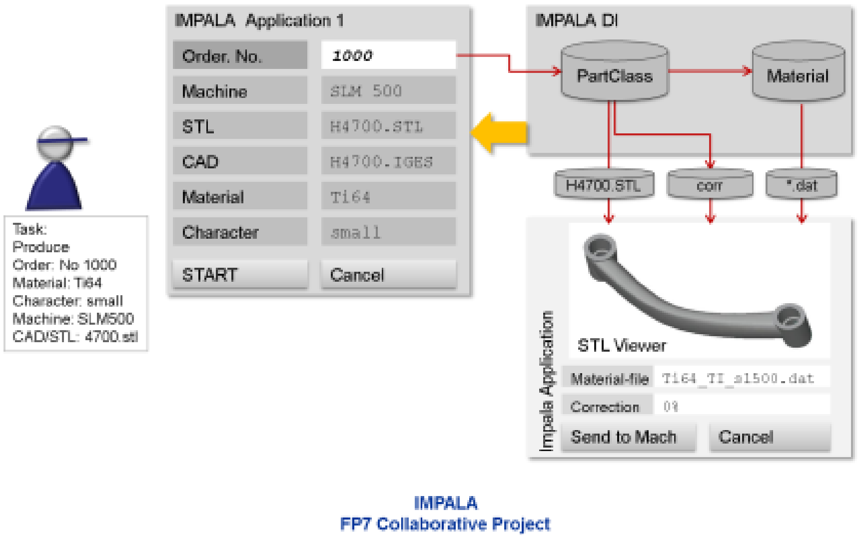


Figure 21 The IMPALA DI.



Task:
Produce
Order: No 1000
Material: Ti64
Character: small
Machine: SLM500
CAD/STL: 4700.stl

Order. No.: 1000
Machine: SLM 500
STL: H4700.STL
CAD: H4700.IGES
Material: Ti64
Character: small

Material-file: Ti64_TI_s1500.dat
Correction: 0%

Figure 22 Example of how the DI could be used post project.

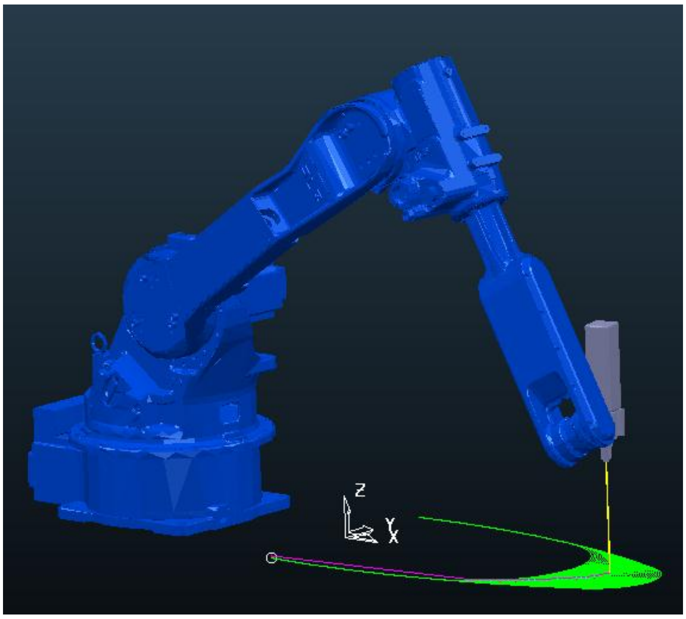


Figure 23 Full laser Tool Path simulation.

Figure 24 To the left is a conventionally produced clad (non-laser) to the right is a laser deposited valve and the centre is a machined OSVAT valve.

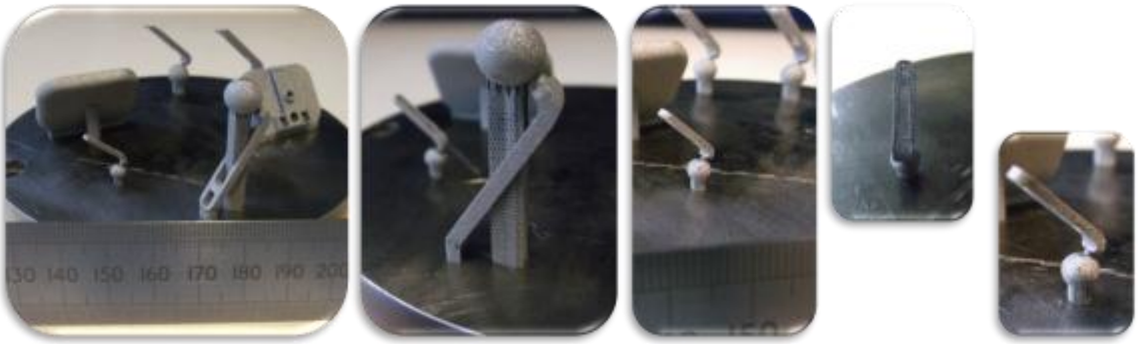


Figure 25 Ball on plate samples produced on the SLM 100.

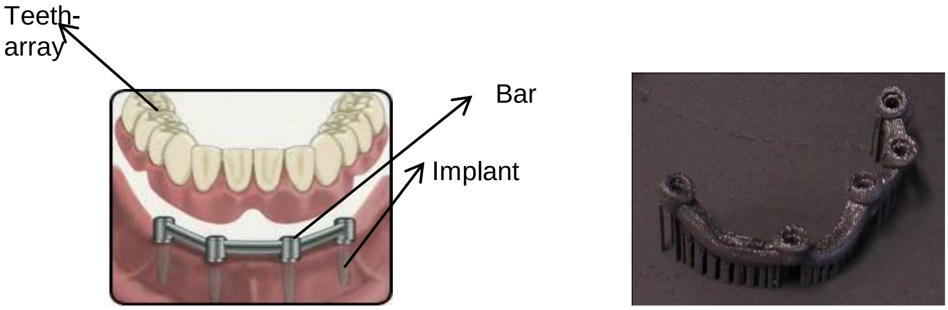


Figure 26 Example of SLM produced dental bridge

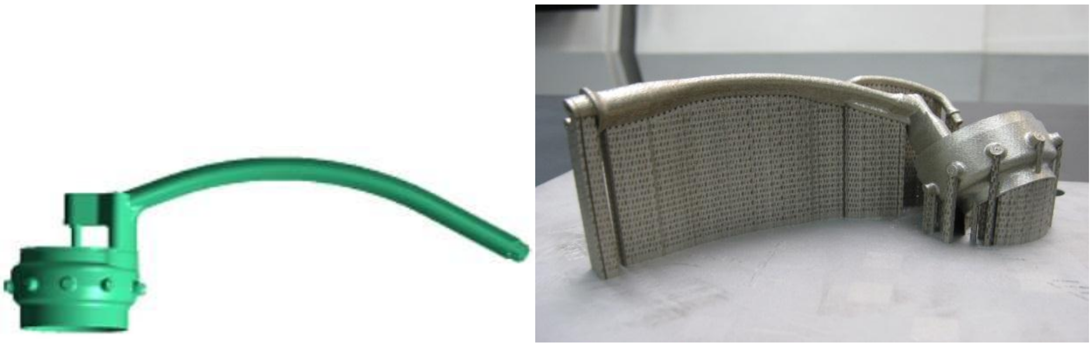


Figure 27 GE combustor component produce from SLM.

Figure 28 Part detached and after a surface finishing.

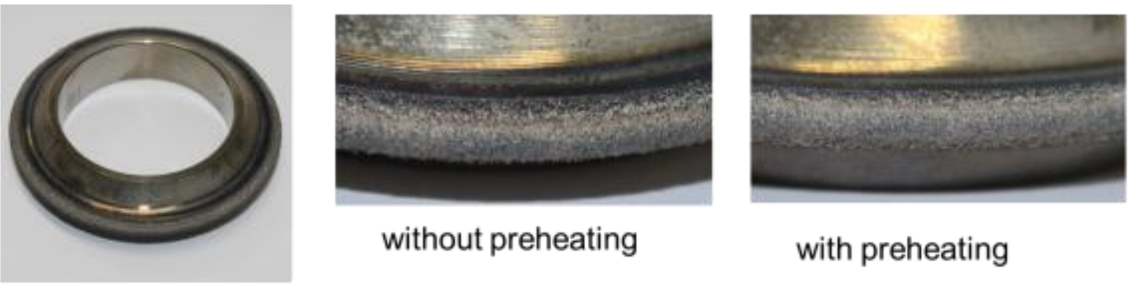


Figure 29 Laser deposited mining disc with and without pre heat.

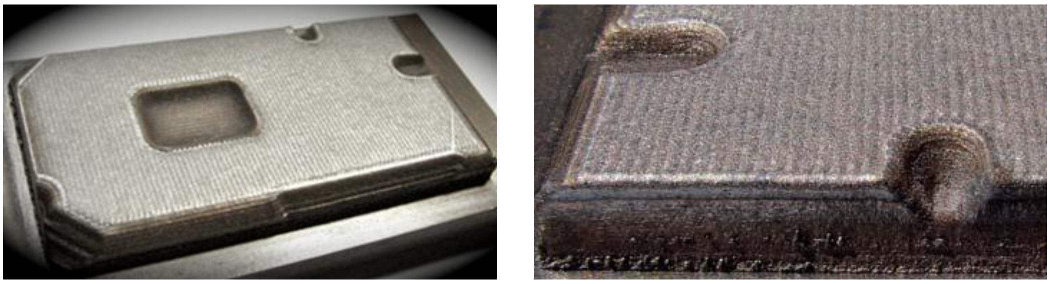


Figure 30 Example of LAMP produced forming press.

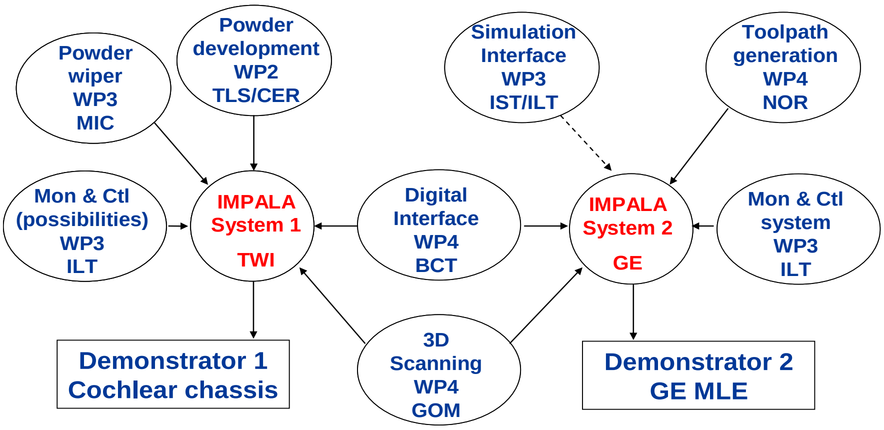


Figure 31 Integration of IMPALA developments into the IMPALA Systems, dotted line denotes activity not to be fully integrated in the system.

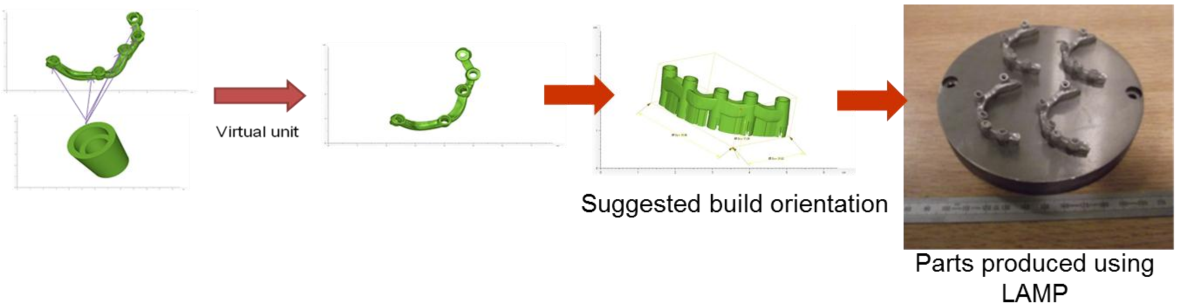


Figure 32 IMPALA customisation objective achieved with the Wisildent dental bridge application.

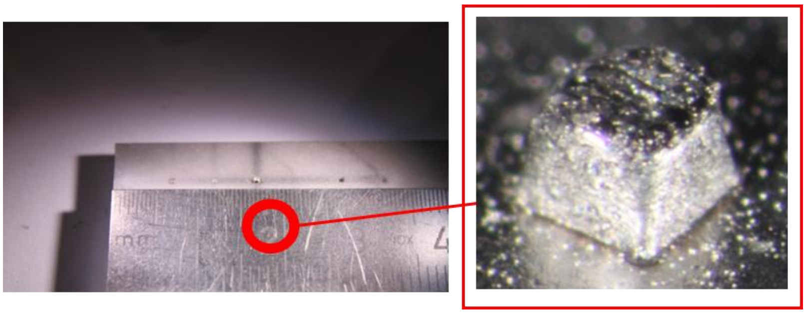


Figure 33 Miniature cube.

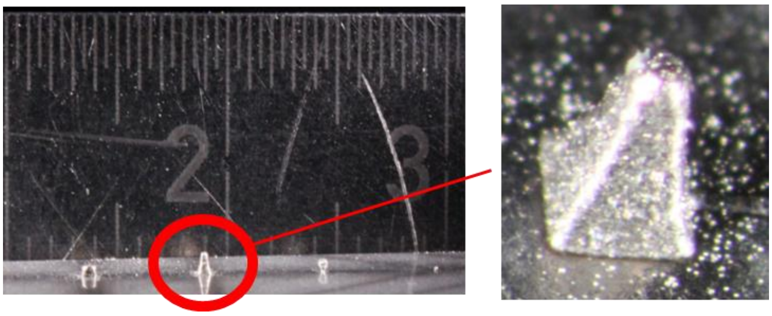


Figure 34 Miniature pyramid.

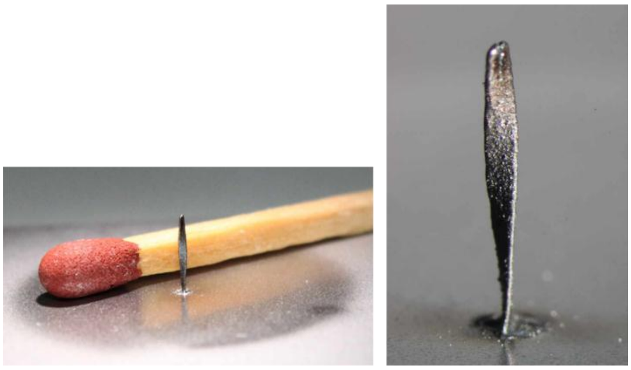


Figure 35 Miniature double helix structure.

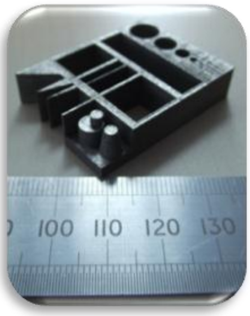


Figure 36 Powder bed demonstrator showing consistent 0.1mm minimum feature size.

Table 1 WP2 Characterisation of IMPALA Results

Results	IMPALA Objectives	Progress beyond State of the art	Novelty	Relating Figures
Aluminium Alloy: Development and Processing	Customisation through widening the range of materials that can be used in AM. Cycle time Deposition rate optimised to around 90cm^3/min giving faster build-up of parts with comparable mechanical properties.	Aluminium alloys are not commonly deposited by laser. This work demonstrated possibilities with newly developed alloy compositions.	New alloy compositions developed and made into powder, processing parameters determined and mechanical properties measured.	8 and 9
Production of fine titanium powders	Reduced particle sized titanium Widening the range of materials that can be used in Additive Manufacturing	Increased yield of fine titanium powder with modified equipment	Fine titanium powders can be made with higher process yields by the use of atomisation equipment modified during the project.	10 and 11
Ceramic and Glass Powder: Development and Processing	Widening the range of materials that can be used in Additive Manufacturing to include materials such as alumina, zirconia and bioglass.	Ceramic and glass are not commonly processed by laser position. This work demonstrated possibilities by producing blocks of the materials. The form of the powder and additives helped in effective processing of the ceramics.	Flowable ceramic and glass powders produced and built into solid blocks by laser additive manufacturing. Introducing capability to produce small ceramic & glass components which are difficult to achieve by conventional methods (e.g. furnace process).	12

Table 2 WP3 Characterisation of IMPALA Results

Results	IMPALA Objectives	Progress beyond State of the art	Novelty	Relating Figures
Assessment of Monitoring system for powder bed process	Accuracy in the range of 2µm can be reached, when measuring the velocity of the TCP on the powder bed. The knowledge of the TCP-velocity allows an accelerated process development for single parts. The knowledge of the TCP-velocity allows an optimisation of the tool path while keeping a constant quality.	Due to the measured velocity the energy input per unit length can be kept constant and ensure steady qualities.	The camera based system provides the ability, to measure scanning velocities at high precision and high sampling rates directly on the powder bed.	

Results	IMPALA Objectives	Progress beyond State of the art	Novelty	Relating Figures
Monitoring system for blown powder deposition	Accuracy in the range of 100µm can be reached, when measuring the width and the length of the melt pool. The concept of image processing makes the system robust against changes in the image acquisition. This means the algorithm is independent of intensity and thresholds, which is a significant advantage for the comparison of monitored signals of different parts. The system gives the possibility to interrupt defective processes in time to initiate corrective processing strategies, and fulfilling the relevant quality assurance documentation requirements.	Signal independent of absorption of thermal emission in the optical path	Visualisation of the melt pool with High Power LED´s. Measurement of the boundary between the liquid and the solid phase.	16,17 and 18
Nozzle improvements	Details down to approx. 30 µm can be build up with the developed equipment; small grained powder in the range of 20 µm can be delivered Precise components and high accuracy as condition for the generation of customised parts High-accuracy of coated details lead to reduced finishing effort	Generation of miniaturised structures down to approx. 30 µm with a high reproducibility are possible	Delivery of fine grained powder particles combined with a small powder spot for miniaturised laser-generated components	19 and 20
SLM powder feeder	Titanium powder in particle size diameters of 5-10, 20 and 30 µm was supplied by TLS. The powder was analysed by CERAM and compared with the 'standard' powder used in SLM, due to the angular shape of the powder it could not be used in the powder feeder. The first steps towards customising the deposition of fine powders by SLM were successful however there needs to be a joint approach with powder manufacturers and OEM suppliers.	Potential to achieve miniaturisation and achieve product with fine details and smooth surface finish. It was established that for processing fine (>10um) powders the most important factor is geometry of the powder particles.	The use of deioniser equipment to improve flowability of sub 20 microns powder particles.	13, 14 and 15
Microcladding System	IST built in collaboration with Micronorma and tested a microdeposition system with vertical powder incidence and	Practical demonstration of the blown powder laser deposition		

Results	IMPALA Objectives	Progress beyond State of the art	Novelty	Relating Figures
	tilted laser beam, intended for microtool repair and biomedical applications. The system was tested by building Ti-alloys and Stellite 6 walls. Small features were built. Repair and modification of punching tools. Tools are submitted to intense wear and shock loading, leading to brittle cracking. Moreover, tools must often be modified in order to comply with product evolution in response to shifting market needs. Lasers are ideal tools for mould repair and modification. Conventional rework techniques include typical high systems downtime and man power effort. These are comprised of either building an insert geometry in the original part that has to be previously prepared for this operation, or manufacture of a new geometry completely. Laser based applications enable a much directed intervention, even for very small sized features, which are mostly the case of product design upgrades. Customized part features within the part geometry using cladding or laser build techniques enable a much more flexible and cost effective application design.	technology.		

Table 3 WP4 Characterisation of IMPALA Results

Results	IMPALA Objectives	Progress beyond State of the art	Novelty	Relating Figures
Digital interface	The DI provides access to process relevant data like material files and CAD models. The integrated application allows the opening these files with suitable programs. Furthermore the specific files can be downloaded from the DB system to the local PC. A better support of the operator	Combination of database and application software tailored to the needs of LAMP processes	Combination of database and application software tailored to the needs of LAMP processes	21 and 22

Results	IMPALA Objectives	Progress beyond State of the art	Novelty	Relating Figures
	and a more transparent handling of the corresponding process information may lead to more reliable processes and therefore reduce the manufacturing time by avoiding scrap production and minimising the trial phase			
LAMP library	Complex LAMP processes using specific powder alloys require a defined set up of the entire process to guarantee the quality of the workpiece. The LAMP library is intended to provide a wide set of information concerning process parameters used in other applications. So the LAMP library can be seen as a knowledge database. While setting up a new process the user is able to refer to other settings used for similar tasks, before. Supporting the user during the set-up means to shorten the time required for this. Especially in low volume production this will shorten the process time.	Collection of LAMP relevant parameters in a single DB system	Collection of LAMP relevant parameter's in a single DB system	
ToolPath generator	Easy to use software interface with automatic tool path generation. System realised as an add on to an existing CAD/CAM system The quick tool path generation algorithm allows production of individual parts or small series in a short time. Graphical representation of the tool path allows for easy control by the operator.	Use of regular CAM software to directly produce tool paths for robots - no external/independent post processor required.	Very fast post processing of big tool paths for 6 axis robots within existing CAM system. Semi-automatic avoidance of singularities. Full simulation capability.	23

Table 4 WP5 Characterisation of IMPALA Results

Results	IMPALA Objectives	Progress beyond State of the art	Novelty	Relating Figures
DLMD for engine valves	The flexibility of Laser Direct Metal Deposition of powder into the valve groove has been demonstrated. It should be possible to design a production level machine to accommodate a wide range of valve sizes, valve materials and groove widths. Low process times for deposition into a groove have	The use of a high power diffractive optic, designed with a specific component in mind and working at 1 micron, for laser direct metal deposition is believed to be a world's first and is significant progress	This work has demonstrated novel use of a tailored energy distribution in the laser beam focus specifically designed for this	24

Results	IMPALA Objectives	Progress beyond State of the art	Novelty	Relating Figures
	been demonstrated with modest laser powers. In addition, the ability with the laser process to produce a much closer near net shape deposit means that the cycle time for the final machining process has been significantly reduced.	beyond the current state of the art.	application	
Ball on Plate Application	Dimensions and surface roughness are not within the specifications. Rework is needed At this stage indicative, normally the end product will be an assembly of two components in a three-step process. If surface roughness and accuracy were improved then there will be a significant impact in cycle time.	Surface roughness might be interesting for laser decoupling and over moulding of parts		25
Dental Bridge Manufacture	Individual customised parts have been designed directly using 3D impression Scan of a patient Production cycle time can be reduced and match the objectives of less than 30 minutes per parts. A finishing of the surface was still necessary after production for this application	Possibility of make an archive of the prosthesis so that, if necessary, it is possible to recreate the same work for the patient. Possibility of input of standard parameters for the connectors of the bar and to input different type of implant (having a DB of different market implants).	New way of production for Wisildent for manufacture of dental implant products, potential IP on new designs in the future	26
Combustor Component	Combustor parts were produced using a CAD file with a powder bed technology. It was very hard to build such thin internal channels with a better surface quality with conventional methods. An additional surface finishing is still necessary. By this new technology, production cycle time can be reduced significantly. Also surface roughness can be optimised by changing the orientation of the parts during the process.	The manufacturing of these combustor parts with powder bed system is a new technology and was conducted successfully. This technology enables to design very complex parts having internal channels and thin walls, leading to innovations for future applications.		27 and 28
Mining disk manufacture	Our cutter tool production consist in a lot of pieces (100 pieces) all the same and a small different kind of product. To increase the tool life of the mining discs an optimised ratio between binder material and the hard facing material (WC) was find out. Therefore different	This technology allows to deposit on steel holder some material like Tungsten carbide. In the mining disk case this technology make possible to deposit		29

Results	IMPALA Objectives	Progress beyond State of the art	Novelty	Relating Figures
	coating strategies were used. Currently the lead time to manufacture one lot of pieces is about two month having the base material in house. The manufacturing time for each face of each piece is not so long (an average of ten-fifteen minutes) but the several required faces also made by external companies increase the time. Using the laser deposition method the lead time would be reduced by 40% cutting down the manufacturing faces number and the costs. Near net shape coating	on the eternal border of the steel ring a uniform hard metal coating strength to wear with desired shape. Rolling tests to analyse abrasion wear behaviour were carried out and have shown positive results		
Forming Press Manufacture	Features included in the geometry of the test piece should be near net-shape which requires a high precision deposition of the added material. Parts and tools include differing geometries as well as varying damages. Well-chosen and specified details that encountered in real parts/tools were build-up. The designed test piece (geometry of Micronorma) was laser-generated with blown powder in high precision. High precision laser cladding reduces pre-machining time due to a near net shape build-up. A time consuming manufacturing process for a whole new part can be prevented.	Re-use of worn tools can be rapidly repaired by high adaptable processing. Damages can be varying from part to part which requires the fast adaption of coating strategies.	Miniaturised details and geometries can be built up with the improved machine set up. Edges and corners, bevels and radii can be build-up in high precision.	30

Table 5 WP6 Characterisation of IMPALA Results

Results	IMPALA Objectives	Progress beyond State of the art	Novelty	Relating Figures
GE MLE	It was aimed to replace the conventional manufacturing method with this new laser process technology to reduce the cycle time and costs. It was constructed Ti metal leading edge process on fan blades to provide an erosion protection, which will be applied to fan blade production. To generate the twisted geometry of the MLE problems of distortion, adherence to the geometric	IMPALA Project provided short cycle-times for part manufacturing, which is a great benefit. For metal leading edge on the blades, it takes only nine hours to finish the part. By conventional methods (milling), it is taking more a week to obtain the final part. Due to the	Reinforcement Structure: to keep distortion very low and to increase stability of the geometry to be build-up the original CAD-data was modified. After remove of the reinforcement structure the desired	32 and 33

Results	IMPALA Objectives	Progress beyond State of the art	Novelty	Relating Figures
	shape and oxidation of titanium were solved.	added reinforcement structure the inner part of the MLE was built-up in a non-stop process. The cladding strategy based on a spiralled tool path with one start point and one end point only. The new method yields time advantages compared to conventional methods as milling.	geometry was obtained.	
CTC Chassis	Dimensions and surface roughness are not within the specifications. Rework is needed. At this stage indicative, hard to estimate as rework is required	Surface roughness might be interesting for laser incoupling and overmoulding of parts		31

Table 6 Data for producing MLE using laser deposition

MILLING				
	Consumed	**Unit Cost***	**Cost***	**Definition**
Raw Material	18 kg	138 €	2484 €	Forged Ti6-4 ingot
Rough Milling	9 hrs	66 €	594 €	Rough Shaping in a 5 axis mill
Measurement and setup	1 hrs	85 €	85 €	Dimensional check and refit
Finish milling	8 hrs	72 €	576 €	Shaping to final dimensions
Final measurement	1 hrs	85 €	85 €	CMM
Inspection	0.5 hrs	86 €	43 €	FPI
		TOTAL:	**3867 €**	

*converted from figures given in US dollars

Table 7 Data for producing MLE using milling

LASER DEPOSTION AND FINE MILLING				
	Consumed	**Unit Cost***	**Cost***	**Definition**
Powder	3 kg	218 €	654 €	Ti6-4 powder
Laser processing	6.5 hrs	73€	475 €	Build up with laser
Measurement and setup	1 hrs	69 €	69 €	CMM and mill fitup
Finish milling	8 hrs	72 €	576 €	Shaping to final dimensions
Final measurement	1 hrs	85 €	85 €	CMM
Inspection	0.5 hrs	86 €	43 €	FPI
		TOTAL:	**1902 €**	

*converted from figures given in US dollars