OPTOMEC®

Additive Manufacturing Systems — from Nano to MACRO™

LENS® Machine Tool Series

Optomec, Inc., 3911 Singer NE, Albuquerque, NM 87109 USA

MADE IN THE USA

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1. PROFILE OF OPTOMEC, INC.

Optomec's breakthrough Additive Manufacturing and 3D Printing technologies are spearheading next generation products in Aerospace, Defense, Electronics and Biomedical applications. These products are highly differentiated for several reasons, primarily: the breadth of materials supported – from structural metals to printed electronics and bio-materials; and, the features these products can produce - from microns to meters.

Optomec is a recognized leader in the field of additive manufacturing, a field with proven advantages in reducing cost, improving functionality, and shortening time to market. Optomec has invested more than $30 million in the development of its leap-frog technology. Key application areas include: extended life of high value aerospace components; reduced size and cost of electronics; and, production of wear-resistant medical devices.

Optomec introduced its first commercial system in 1998, and has since installed more than 200 systems worldwide. Our marquee user base includes leading manufacturing companies such as GE, Corning, Boeing, Lockheed, Saturn, TE Connectivity, Panasonic, Samsung, Bosch and Xerox with additional installations at NASA, the US Army, US Air Force and more than 30 leading universities.

Optomec is a privately held company, with headquarters located in Albuquerque, New Mexico, and an engineering facility in Saint Paul, Minnesota. Field sales offices are located throughout the United States along with a global network of distributors and agents. Optomec currently has 65 employees, an experienced management team and substantial Intellectual Property assets with more than 40 patents issued and 60 pending.

PRODUCTS

Optomec's commercial LENS™ and Aerosol Jet® systems are proprietary additive manufacturing technologies utilized for cost-effective development, production, and repair for a wide range of end-products. The Optomec Professional Services team works closely with our customers and partners through application development projects and system support services to ensure end-user success.

LENS SYSTEMS

LENS systems utilize high power laser processing to fabricate and repair high value metal components in materials such as titanium, steel and Inconel®. The LENS process is used in a range of Aerospace, Defense and Medical applications, including: the Repair of gas turbine engine components; Cladding; and, Production of titanium hardware.

AEROSOL JET SYSTEMS

Aerosol Jet is largely used for printable electronics applications. This technology is capable of precise deposition of nanomaterials for fine-feature circuitry, embedded components and miniaturized devices. Application areas include the repair and manufacture of: Display Electronics; Antenna and Sensors; Flex Circuits; and, Bio-depositions for Drug Discovery.

2. LENS® TECHNOLOGY

LENS is an additive manufacturing process for fabricating, enhancing, and repairing metal components directly from CAD data. The LENS process can effectively build 3D structures with excellent material properties from a wide range of metal powders, including titanium, stainless steel, nickel, cobalt and other engineering alloys.

Since licensing this technology from Sandia National Laboratories in 1997, Optomec has made proprietary process and control enhancements to develop robust, commercial systems. LENS applications include Repair of high value parts, Rapid Manufacturing, and Value-Added Manufacturing. Systems have been deployed in the Aerospace, Defense, Power Generation, Industrial and Medical equipment manufacturing industries.

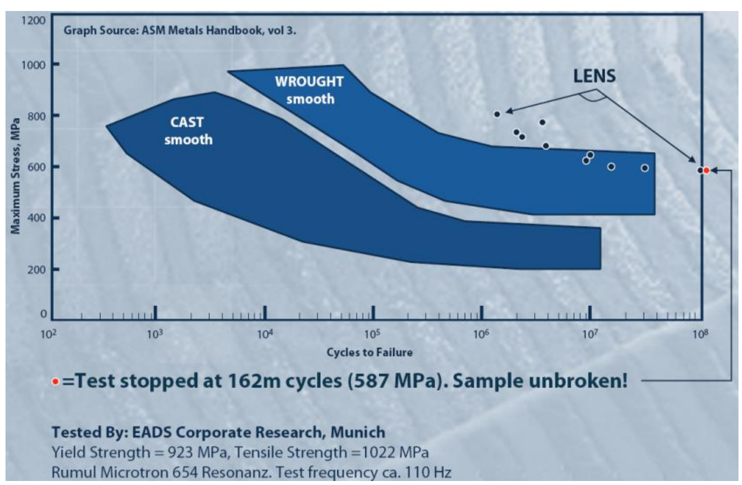
Repair: The LENS process offers cost and functional advantages for repair applications because it can uniquely add small amounts of material to worn or fractured surfaces. LENS is a highly targeted repair approach, and it exposes the part to far less heat than conventional techniques, avoiding damage to the entire part while repairing a specific area. The Heat Affected Zone (HAZ) generated by the LENS process is significantly less than that generated by welding processes such as TIG, MIG, or Plasma Arc. A LENS repair has exceptional material properties and interface characteristics, which can exceed those of the original material. A LENS repair can often outlast the original surface, and reduce the frequency of future repair procedures.

Rapid Manufacturing**:** LENS is ideal for Rapid Manufacturing applications because it has the flexibility to fabricate superior metal components in less time and at lower cost than alternate methods. LENS is also a flexible manufacturing tool that can produce components of novel shape, structure, and material composition, empowering engineers to design better products with improved performance. Fully-functional prototypes can be made with LENS, so that form, fit and function can all be tested with the appropriate material.

Value-Added Manufacturing: LENS can be a valuable addition to a conventional manufacturing process. Examples include using LENS to add features to a casting that are difficult to cast, but easy to LENS. Alternatively, LENS can be used to rework mis-processed material, thus decreasing scrap rates. Further value can be obtained by using LENS to add protective coatings to a component – graded coatings or hard-facing to reduce wear.

Materials Used Commercially			
Alloy Class	**Alloy**	**Alloy Class**	**Alloy**
Titanium	CP Ti	Tool Steel	H13, S7
	Ti 6-4	Stainless Steel	13-8, 17-4
	Ti 6-2-4-2		304, 316
Nickel	IN625		410, 420
	IN718	Aluminum	4047
Cobalt	Stellite 21		
Materials Used in R&D			
Alloy Class	**Alloy**	**Alloy Class**	**Alloy**
Titanium	Ti 6-2-4-6	Tool Steel	A-2
	Ti 48-2-2	Stainless Steel	15-5PH
	Ti 22Al-23Nb		AM355
Nickel	IN690		309, 416
	Hastelloy X	Copper	GRCop-84
	Waspalloy		Cu-Ni
	MarM 247	Refractories	W, Mo, Nb
	Rene 142	Composites	TiC, WC, CrC

LENS Ti 6-4 Fatigue Results (EADS Corp. Research, Munich)

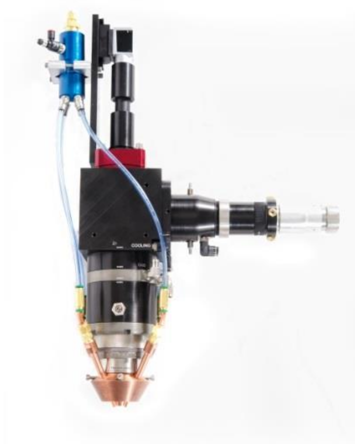


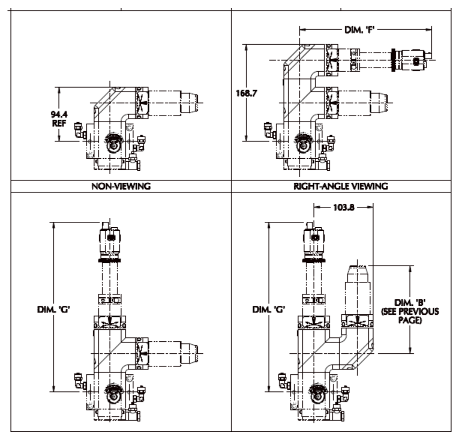
3. LENS® PRINT ENGINE

The LENS Print Engine ('LPE') is the heart of the LENS Machine Tool Series. It contains a set of state-of-the-art components which together drive the core LENS Additive Manufacturing process. The LPE can take different forms depending on options and system integration. The primary function of LPE components are as follows:

A) LENS Processing Head ('LPH') with SMARTAM™ Technology:

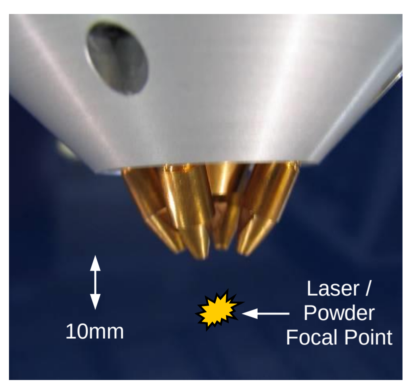
1) The LPH is the primary tool for delivering laser energy to the deposition zone. It consists of collimating and focusing lenses which deliver laser power from the laser's fiber connection through to the deposition area (see below left).
2) The laser spot size can be adjusted manually. This adjustment is useful when depositing at higher or lower power.
3) The LPH is a water-tight assembly to allow for operation in a wet, machining environment.
4) The LPH is water-cooled and supports fiber laser power options up to 3 kW.
5) In addition to the laser fiber connection, the LPH can also be outfitted with SMARTAM technology, a closed loop control that automatically adjusts laser power during a build to maintain constant melt pool area. SMARTAM ensures tight additive manufacturing process control to ensure consistent metal quality. The assembly is offered in straight and right-angle configurations depending on system integration requirements (see below right).





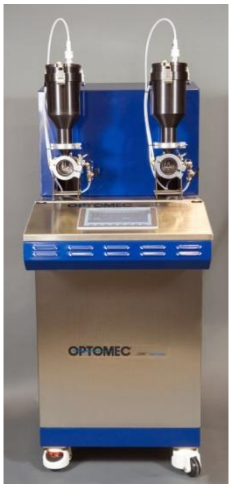
B) LENS Print Nozzle ('LPN'):

1) The LPN is designed for powder delivery to the deposition zone. It mounts onto the end of the LPH as seen, in action, (see below left). A close up of the powder nozzles can also be seen (below right).
2) The LPN delivers purge gas to the deposition zone to free the area of debris as well as provide a protective shroud of argon for any reactive powders being processed (titanium, etc.).



C) LENS Powder Feeder ('LPF'):

1) The LENS system uses a proprietary **STEADYFLOW™** powder feed mechanism controlled by the rotation of a wheel through the powder reservoir. This design allows extremely steady flow of powder at rates commonly used for the LENS process.
2) The LPF is able to feed a wide range of commercially available powders. For the most demanding part quality requirements, spherical, inert-gas-atomized or plasma-rotating-electrode-atomized powders are recommended.
3) The LPF is exceptionally stable at low powder feed rates, offering outstanding control at rates less than 1 gram per minute.
4) Two LPF units are commonly used and can feed the LENS Print Nozzle simultaneously or independently. This enables the production of gradient materials, where one material is transitioned to another through the build. Alternatively, it can be useful to keep two different materials loaded for easy switching as needed.
5) One or two LPF units are provided in a standalone cart as shown below (lower left picture). The LPF units can also be delivered as separate components for side-mount on the machine tool depending on integration options (below right).



D) Laser:

1) The LENS Print Engine currently utilizes a Fiber Laser. This offers many benefits over other laser types including, low electrical power consumption, long life, high beam quality, and maintenance-free operation.
2) Lasers delivered with the LPE vary depending on laser power options and integration options: air-cooled rackmount unit (below left); or, standalone laser (below right) with laser chiller (not pictured).

4. LENS® MACHINE TOOL SERIES

The LENS Machine Tool Series consists of a LENS Print Engine packaged with a production grade CNC Machine Tool platform. There are two primary systems offered in this product series: the LENS Additive Manufacturing Tool (LENS 3D AM); and the LENS Hybrid (LENS 3D Hybrid). The LENS 3D AM is strictly for Additive Manufacturing while the LENS 3D Hybrid provides both Additive and Subtractive manufacturing capabilities all on one system.

A) LENS 3D Additive Manufacturing Tool:

1) The LENS 3D AM is built on a rugged vertical milling platform with the LPE mounted in place of the Z-axis spindle.
2) The baseline table size is 16 inches X 50 inches and the system has a working envelop of 40 X 20 X 22 inches. Larger platforms are available upon request.
3) The system is designed with a Class I Laser enclosure and provides viewing through a laser safety window. The access doors and ports are interlocked to prevent possible exposure to the high-power laser beam during normal operations.

B) LENS 3D Hybrid:

1) The LENS 3D Hybrid includes all the elements of the LENS 3D AM with the addition of traditional subtractive machining capability all in one Hybrid Manufacturing system.
2) The machining capability is provided with the inclusion of the traditional vertical mill, Z-axis spindle and, a 16-tool, armless tool changer.
3) The LENS 3D Hybrid has a baseline table size of 13 inches X 50 inches and a working envelop of 30 X 16 X 20 inches. Larger platforms are available upon request.
4) The LENS 3D Hybrid is designed with a Class I Laser enclosure and provides viewing through a laser safety window. The access doors and ports are interlocked to prevent possible exposure to the high-power laser beam during normal operations.

Control information and machine tool options for both AMT and HVM systems are provided below.

CONTROL:

Centroid M400 control

AC brushless servo motors

Operator console with 15" color LCD screen

PC based control with Windows 7 OS
Standard G and M code execution
On screen color 3D graphics
Job execution time estimation
Conversational programming (Intercon)
Solid state hard drive
Dual digital processor system for
high block throughput (600 blocks per
second) and 2000 line look ahead
for high speed machining
Digital servo amplfier
with optic fiber interface
Spindle on/off and RPM control
Programmable coolant pump and
lubrication pump control
4MB basic program memory
USB and Ethernet ports
Multiple work coordinates (G55-G59)
Macros and subprograms

SOFTWARE OPTIONS

Coordinate system rotation
Scaling and mirroring
Spindle orientation
DXF import
Unlimited Program File Size

OPTIONAL ACCESORIES

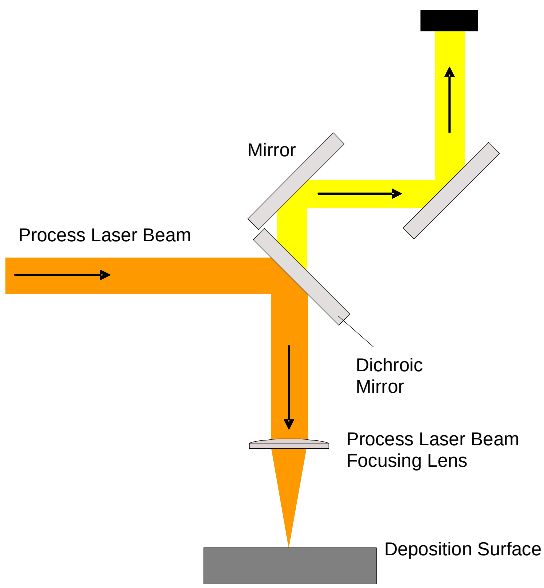
Tool touch off TT-1
Probing and digitizing DP-4
4th axis (rotary table)

5. SMARTAM™ MELT POOL SENSOR OPTION

While the LENS process is robust and stable in open-loop processing, many customers demand a higher level of operation possible with closed-loop control. This is achieved in the LENS process through the use of Optomec's proprietary SMARTAM Melt Pool Sensor Option.

SMARTAM Overview

Optomec SMARTAM technology consists of special focusing optics, control software, and a proprietary Melt Pool Sensor (MPS) as described below. A key feature of the MPS is its location in the optical system and its birds eye view of the deposition zone.



Schematic representation of the MPS.

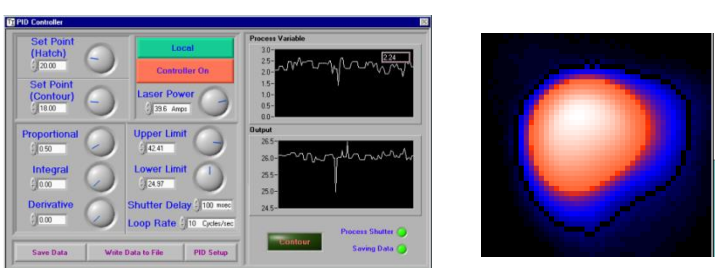
The laser beam (orange) is directed by a dichroic mirror and is focused at the deposition surface.

The light emitted by the melt-pool is collimated by the same focusing lens, and passes through the dichroic mirror (yellow).

Principle of Operation

SMARTAM Technology is used to maintain a constant melt pool size. A camera views the molten pool - a typical image is shown below (middle). The area of the molten pool is calculated, and the area is compared to the user-set value. If the area is smaller than required, the laser power is increased appropriately to increase the size. Similarly, if the area is larger than required, the laser power is decreased. In this way, the area of the molten pool is kept constant throughout the build.

The key benefit of this approach is to control the heat input so it is consistent from run to run and throughout the build. The properties of the deposited material are highly influenced by the microstructure of the material which is principally influenced by the cooling rate. In turn, the cooling rate is principally influenced by the melt-pool area. Thus, SMARTAM Technology is able to ensure consistent properties throughout the build. This closed loop control is particularly useful if dealing with rapid changes in cross-sectional area, or changes in composition, such as when depositing gradient materials. It can also be useful to ensure adequate heat input to the first few layers to help eliminate Lack-of-Fusion, while not providing too much heat later in the build which can lead to defects or poor microstructure.



SMARTAM User Interface, and representative melt-pool image. The black-line in the melt-pool image shows the user-set threshold, which is then monitored by the system to keep the enclosed area constant through the build.

> *"Please pass on my hearty "kudos" to the folks working on the SMARTAM Melt Pool Sensor. I made an H-13 - Copper graded material and H-13 - Nickel - Copper graded material today using the MPS and the dimensional tolerances are excellent.*
>
> *I was previously unable to make a quality H-13 - Copper deposit due to the widely varying thermal conductivities of the two materials (Cu thermal conductivity is about 13x greater than H-13 steel)"*