Upsizing AM Build Capacity: Options and Tradeoffs for Machine Builders

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Keywords: DLP Micro-mirror Array, Maskless Lithography, Additive Manufacturing, Powder Bed Fusion

ABSTRACT

DLP UV projectors have become a standard in SLA Additive Manufacturing (AM) machines, typically using a single projector in a static configuration. Larger print volumes are compromised in pixel resolution and power density. Productivity and manufacturing scalability of such static configurations is limited. The paper will discuss a multiple scrolling projector configuration to overcome the limitations, enabling efficient scalable volume production.

Polymer Powder Bed Fusion (PBF), using focused laser beams to melt polymer powder into 3D-printed objects is facing similar challenges of product consistency, scalability and production throughput. This paper presents a system approach based on Visitech's recently introduced Direct Image Scrolling (DIS) technology and will compare and discuss first test results performed with 3D-printed parts from this process.

1 Introduction

A vast number of applications of DLP (digital light processing) technology is established in visible spectrum applications, including beamers in projection applications, industrial projectors for 3D metrology, structured pattern illumination in microscopy and many more. In addition, dedicated DMD (digital micro-mirror device) models with different optical characteristics and FPGA-driven controller electronics have been introduced for implementations in non-visible industrial applications, such as UV Direct Imaging lithography and DLP-based additive manufacturing (3D print). NIR DMD variants have been available for quite a while, but their limitations to withstand higher levels of NIR radiation limited their use to fields such as NIR spectroscopy and other low power system. The recent introduction of the DLP650LNIR chip, accepting up to 150 W of NIR radiation on the DMD, enables new opportunities for high power systems.

1.1 DLP-based SLA machines in rapid prototyping

During the past years, DLP-based SLA (stereo lithography) 3D print has been established as commonly used technology in rapid prototyping. Typical configurations – either desktop or floor-based machines – comprise a DLP projector with UV-LED and projection optics, featuring the desired pixel pitch in image plane, the vat for the photosensitive resin, a z-motion stage and related machine control systems and software. Resolution of the DMD and the desired feature size have an immediate impact on the maximum size of the 3-D printed product. Efficient up-scaling from rapid prototyping into additive manufacturing and volume production is heavily compromised by the limited vat size in such static single projector implementations.

1.2 NIR Polymer PBF

Established Polymer powder bed fusion machines are using the classical SLS (selective laser sintering) process with a pre-heated powder compartment and a focused laser. The laser heats the polymer powder above the melting point, by address each single point in a layer sequentially. To accelerate the process that heavily depends on the fill factor, multiple lasers could be used. This drives costs and complexity of a system. More importantly, the sequential addressing of voxels to be melted, and variations in fill factor have a strong impact on time per layer and with that negatively impact compound strength and other mechanical properties of the printed parts.

2 Scrolling multi-head systems in UV-SLA

Scaling up build size and enlarging vat area is an essential requirement that can't be solved with single projector configurations without compromising power density or voxel size. Even stacking multiple projectors statically is often challenged due to the footprint of each individual projector. In addition, compromises on power density and/or pixel pitch are applicable. Scaling up productivity through simple multiplication of 3D printers with static projectors lead to challenges in factory logistics and would consume floor space, operator capacity, and investments.

2.1 Basic configuration and features

Direct imaging (DI) PCB lithography sketches out the path for a solution in the AM world [1,2]. To meet speed and throughput requirements of the industry, configurations with multiple stacked photohead projectors, properly aligned and installed in x-y motion systems, efficiently expose even 60”x60” panels. The processes run reliably even in 24/7 operation.

The native pixel pitch in PCB lithography systems is typically 10 µm and below, i.e. about 5 to 10 times smaller than in typical AM applications. Due to light engine footprint, then each projector in the stack must expose multiple stripes. In Additive Manufacturing, the pixel pitch is typically an order of magnitude larger. At 50 micron and above, it is then possible to build stacked and stitched configurations within a single axis motion system.

Fig. 1 AM subsystem with multiple projectors stacked in 1-axis motion system

To illustrate how efficiently the configuration in Fig. 1 can scale up build size, an example might help:

The native image size of a projector at 50 micron is 96 x 54 mm^2. To cover an accumulated vat area of 0,5 m^2 with static projectors, a total of 96 machines would be needed, occupying a massive floor space, and demanding for multiple operators to monitor the processes and maintain equipment. And still the maximum size of printed objects is limited to the native image size of a projector at 96x54 mm^2. With a scrolling multi-head system, the same vat size and pixel resolution of 0,5 m^2 is achieved with a 5 heads configuration, occupying less than 4 m^2 of floor space and a single operator (Fig. 2). Even at moderate scroll speeds, the projectors’ power output well meets the requirements of established photosensitive resins.

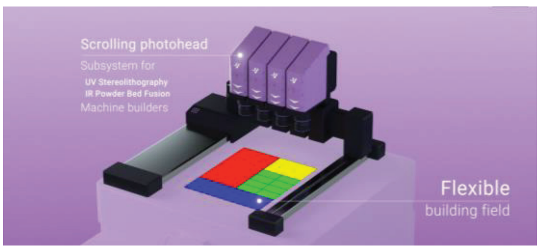

Fig. 2 Vat segmentation options in a multihead scrolling system

Given that typical layer process times, consisting of exposure time itself plus layer preparation times, are very similar in a machine with static projector and a scrolling machine, the productivity of a 5 head scrolling machine would compare closely with the production output of almost 100 printers with static projectors, an up to 20 times improvement.

2.2 Advanced options with PPC and SPX

The installation of projectors efficiently scales not only the vat area with a much smaller number of projectors. Fig.2 illustrates the flexibility in vat segmentations to precisely fit the specific needs of objects in production.

Critically, the motion system allows implementation of our patented feature Pixel Power Control (PPC) that enables precise tuning of power uniformity across image and across the stitching zones between projectors allowing consistent and predictable irradiance into the image plane.

Another advanced feature is the Subpixelation (SPX) feature, using optical multiplexing to improve minimum feature size, shape, and surface finish of 3D printed components. Fig. 3 illustrates the smoothness of a curved surface at different levels of subpixelation in simulation and in electron microscopy images of single layer prints. This eliminates the need nearly all post-processing for smooth edges for typical print resolutions.

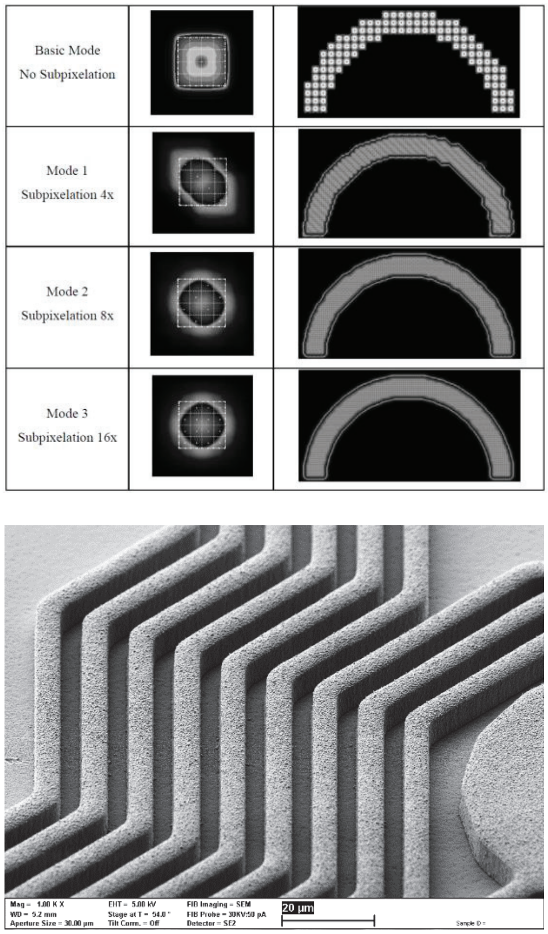

Fig. 3 Simulation of different subpixelation levels on curved surfaces and electron microscope images of printouts.

3 Polymer PBF with Direct Image Scrolling

Production process consistency within polymer powder bed fusion with direct laser fusion systems is critical due to variations in layer-by-layer process time and sequential addressing of individual voxels. This tends to deteriorate the properties of material compound within a 3D printed component, such as density, layer to layer adhesion, stress, and shear strength. A viable path to escape layer-to-layer process variations would be the Direct Image Scrolling technique.

3.1 Direct Image Scrolling technique

The availability of a high power NIR DLP display enabled the development of a high power NIR projector [3]. The ultimate goal of such a product development is a projector with integrated light source, but for first experiments a projector was developed, that was fed with 400 W fiber coupled NIR 1064 nm laser (Lumics LuOcean M4). Careful design of the optical system was required to overcome especially the thermal challenges around the DMD [4,5]. Given the thermal conductivity limitations of the DMD structure, special demands are exhibited to the thermal management. Not only is comprehensive cooling needed for the optical path including the Dump light area of the DMD, but most importantly the glass window of the DMD needs additional air cooling to prevent damage of the pixel array. Visitech's LRS-MCx-WX NIR light engine was then the world's first NIR DLP projector imaging almost 100 W of NIR power into the image plane of the projector.

3.2 Experimental setup

A commercially available SLS machine (Sinterit Lisa Pro) was modified. The preheated compartment and the powder handling system was re-used, while the original SLS laser and the original machine cover were removed and replaced by a quartz glass plate. The DLP-based DIS subsystem was placed to project a 2D image into the powder bed.

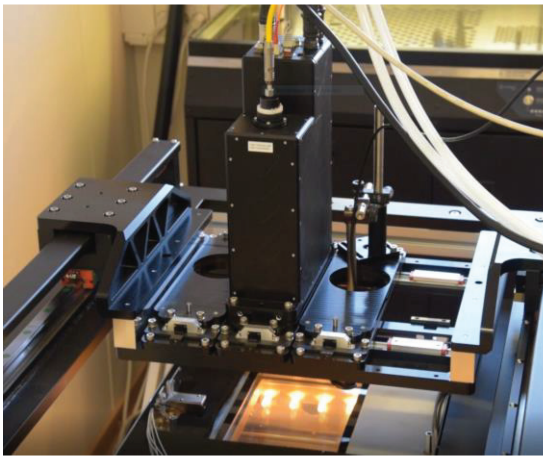

Fig. 4 Experimental setup with Light Engine

Imaging lenses with different magnifications were used to identify the sweet spot for image size versus power density to melt and fuse the powder particles into a 3D printed compound. Experiments were made with PA12 powder from Sinterit. Variation of parameters such as compartment temperature, power density settings and exposure times were firstly tested and elaborated with a static projector. This aimed at identifying the sweet spot for settings at 75 µm pixel pitch, identifying it at about 80 W of power in image and with around 2 to 4 seconds of exposure time.

To then enlarge build size, the projector was placed on a linear motion system, extending the build size to the maximum of the powder bed size of the Lisa Pro machine. This enabled printing of components typically used in mechanical property testing.

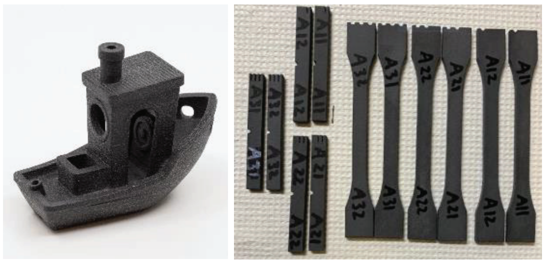

Fig. 5 Printed component (l.) and test samples for lab tests (printed with different orientations in powder bed; r.)

3.3 Properties of DIS printed components

Samples from the experimental setup, printed with different parameters and at different orientations in the powder bed were delivered to a test lab together with an equivalent set of samples produced on an original Sinterit Lisa Pro machine at the machine manufacturer's site. The test lab executed stretch and extension tests in accordance with ISO 527-2, Shards according to ISO 179-1 and Shore D according to ISO 868.

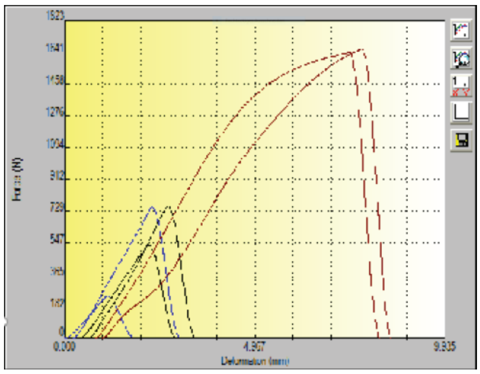

Fig. 6 Samples in stretch test showing enhanced performance of DIS printed over SLS samples (dependency on orientation in powder bed is seen)

The results of the tests exhibit a significantly enhanced compound density and strength of the components printed with DIS, as well as significantly enhanced stretch and extension properties.

4 Conclusions and outlook

System configurations with scrolling multi-head projectors offer significant opportunities for the development of productivity optimized system both in the field of UV-SLA as well as in Polymer powder bed fusion.

4.1 Outlook Scrolling Multi-head UV-SLA

Scrolling multi-head configurations are considered a viable approach to efficiently scale up productivity, without adding drastic investment in equipment multiplication. In addition, product consistency is significantly enhanced while production occurs on same machine with established process. External handling equipment can be scaled down due to significantly reduced floor space. Excellent scalability is provided by scalability of the motion system, flexible numbers of light engines in installation and different projection lens types, helping to tune the configurations precisely to the individual product and production requirements.

4.2 Outlook NIR Direct Image Scrolling (DIS)

Visitech is in the final stages production release of a self-contained high power NIR projector solution and software, comprising not only all the optical and electrical control system, but also an integrated 400 W NIR Laser Diode module and motion control software.

Fig. 7 Light engine LRS-MCx WX NIR (left) with integrated high power NIR Laser diode module (right)

This will strongly advance implementations with DIS technology in Polymer powder bed fusion and help scale up productivity and product properties. Projects with machine makers are in preparation for more professional test environment implementations, allowing for a more structured and advanced evaluation of DIS print processes and their parameters.

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