**Company Overview**

3D printing technologies such as Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), and Stereolithography (SLA) are potentially disruptive manufacturing tools that enable complex form factors with micrometric precision.[[1]](#footnote-1) Light-activated 3D printers, including SLA and Direct Light Projection (DLP) based systems, are particularly desirable as manufacturing tools because of their high print speeds, reduced energy requirements, low waste generation, and enhanced part finish quality.[[2]](#footnote-2) The Department of Energy’s Office of Energy Efficiency and Renewable Energy estimates that > 50% energy savings and 90% material and cost reduction can be achieved by integrating additive manufacturing techniques into mainstream manufacturing.[[3]](#footnote-3) Recent developments in 3D printing such as accelerated print time-scales and lowered print costs have unlocked access to these powerful manufacturing tools for a broader audience.

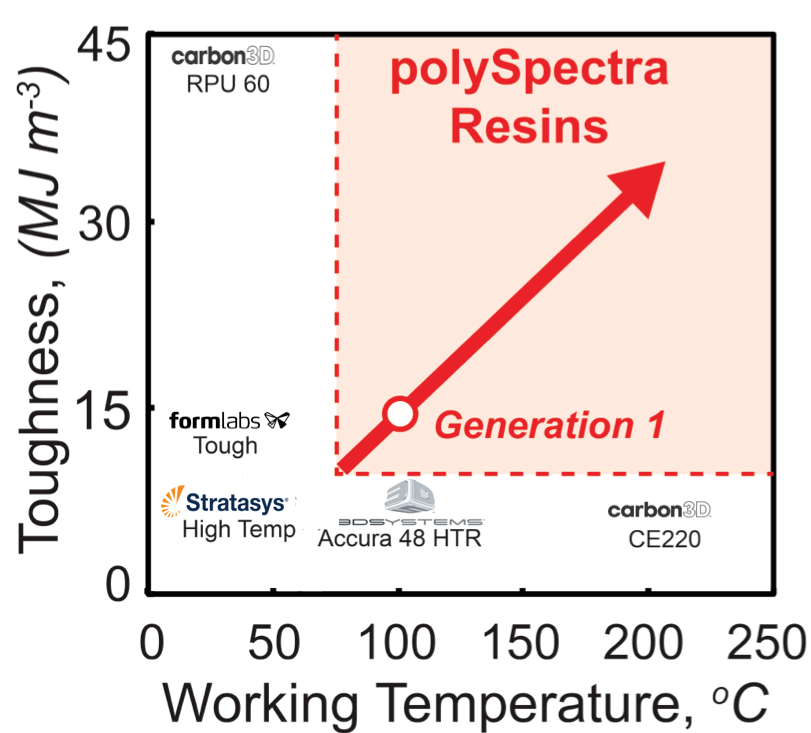
The utility of light-activated 3D printing in manufacturing is severely limited by the lack of printable functional materials. There are very limited cases where the quality of printed materials can match machined or injection-molded parts. Most SLA printing material chemistries currently available in the market result in brittle parts that deform at temperatures >60 oC, with limited options to tune the chemical functionality and mechanical performance.[[4]](#footnote-4) As a result, the vast majority of commercial uses for 3D printing today are in rapid prototyping, not manufacturing. **The single biggest challenge to realizing direct fabrication of functional parts is the limited scope of materials chemistry available in today’s 3D printers.**

polySpectra has developed a new class of modular light-activated resins, capable of manufacturing microstructured materials with tailored geometry and chemical functionality in a single step. We refer to this process as *functional lithography* – the ability to simultaneously define the form and function of advanced materials and devices. The application of functional lithography to additive manufacturing would enable production-ready parts to be directly 3D-printed, whereas existing printers typically make prototypes, mock-ups or toys. Our patented chemistry, termed PhotoLithographic Olefin Metathesis Polymerization (PLOMP), opens up a completely new set of materials possibilities for 3D printing. PLOMP leverages a unique light-activated catalyst, which is highly selective for the olefin metathesis reaction. As a result, we can incorporate dozens of unique organic and inorganic additives into our resins allowing for tailored multifunctional materials with micro- and nanostructured geometries. While our initial focus for a first product is to develop a resin capable of printing high-performance structural composites analogous to existing thermosets, PLOMP enables us to print tailored advanced materials with no existing commercial analogs. polySpectra will unlock the true potential of the existing 3D printing ecosystem with our novel multifunctional material platform: democratized advanced additive manufacturing.

**Problem Definition**

The major technical challenge we face is application-based product development. While our company has tremendous technical resources in materials chemistry and photopatterning, we lack expertise in the manufacturing sector to independently develop high-impact applications for our technology.

We initiated an intensive customer discovery effort directed to identify significant challenges in the additive manufacturing industry. We used Figure 1 as part of an executive summary to conduct more than 100 customer interviews. We discovered a serious unmet need to be able to directly manufacture production parts with the mechanical and thermal properties of thermoplastics and thermosets. We have been asked for resin samples from a number of high-profile 3D printing companies, including HP, Carbon3D, and Formlabs. Many reputable companies have asked us for qualification parts, including GE Aviation, Autodesk, SpaceX, Protocafe and Nacent Objects. Our conversations with resin suppliers 3D Systems and Sartomer confirmed that *everyone in the industry is looking for new chemistry*. Additive manufacturing leader Stratasys told us, “If you could hit the performance of thermoplastics with the resolution of SLA, that would be the holy grail of 3D printing”. We also completed the Bay Area Regional NSF Innovation Corps customer discovery course and identified the market need for 3D printed parts with properties and metrics comparable to conventional tooling.Although these validations are helpful, we require collaborative expertise in the manufacturing sector to develop our materials towards high-impact applications in advanced additive manufacturing, specifically rapid tooling.



*Figure 1. Schematic indicating the unmet need in the 3D materials market resolvable by polySpectra materials.*

To surmount this technical challenge, we hope to collaborate with advanced manufacturing experts on engineering-oriented product development efforts. Here, we propose to collaborate with the Manufacturing Demonstration Facility (MDF) at Oak Ridge National Laboratory. The MDF is a world-class research facility for advanced additive manufacturing. Through this Small Business Voucher, we propose to work with the scientists and engineers at the MDF to further develop our functional lithography technology towards high-impact manufacturing challenges. **Specifically, we propose to work with Dr. Lonnie Love and Dr. Amy Elliott towards applications of our unique photopolymers in rapid tooling.** We believe that our resins have the ability to make low-cost, high-throughput, high-resolution molds and dies for injection molding and high-performance carbon fiber composite part manufacturing. The main objective of the SBV grant is to verify this hypothesis by working with experts at ORNL & MDF.

**Project Impact**

Conventional tooling for injection molding is expensive, low-throughput, and time intensive. For example, injection molds for microstructured parts often cost more than $100,000, because they require high-precision machining. Turnaround times for these high-precision molds, tools and dies can often be > 8 weeks, because they require multiple iterations and modifications to the tool before it can go into production.

polySpectra’s functional materials can have a tremendous impact on the manufacturing industry by enabling low-cost, high-throughput, and high-resolution molds. Currently, polySpectra’s printed parts would cost < $1000 to manufacture, with turnaround times of < 1 h. **For micromolding tools - this translates to cost savings of >100x and time savings of >1000x**. Our functional lithography process also offers resolutions < 75 microns and the ability to directly incorporate surface functionalities during printing, thereby reducing post-manufacturing processes. Our photopolymer resins have the potential to disrupt the rapid tooling industry, due to the following advantages:

* Mechanical properties comparable with high-performance thermoplastics including high toughness and machinability with low brittleness demonstrated by elongation at break *ε* > 15 % at Modulus *Etensile* > 2 GPa and Ultimate Tensile strength *UTS* > 50 MPa.
* High operating temperature with *T*g values > 150 oC.
* Chemical inertness to tolerate corrosive solvents and hazardous chemical conditions.
* Ability to continuously print structures avoiding the layer-by-layer approach, eliminating typical print anisotropies and layer adhesion problems.
* Facile manipulation of material chemistries allowed through the modular incorporation of functional additives, including inorganic additives for improved mechanical properties.

A collaborative process-development effort with MDF would dramatically increase our chances of meaningful market penetration by giving polySpectra a tremendous competitive advantage. This collaboration will help us to prove out end-use applications in our target first market, address the critical technical metrics, and validate printed parts. Furthermore, product testing by the MDF will validate our claims to the market and help elevate our breakthrough technology to a viable manufacturing product. We have developed the following timeline for product development in collaboration with MDF:

|  |  |  |
| --- | --- | --- |
| **Months** | **Description** | **Completion criteria** |
| *Pre. 0 ✓* | * Successfully 3D print high performance parts using PLOMP and off-the-shelf hardware | * polySpectra is already printing parts with working temperatures >125 °C and (*ε*) > 20 %. |
| *0 - 3* | * Proof-of-concept: use functional lithography to print tooling for injection molding | * polySpectra directly 3D prints mold inserts for MDF to test with injection molding equip. |
| *3 - 6* | * Process development: work with engineering staff to install stereolithography hardware at MDF and test polySpectra resins | * Install compatible printer and necessary equipment at MDF. * Validate quality of printed parts and compare quantitatively to parts printed by polySpectra |
| *6 - 9* | * Application development: Validate rapid tooling applications for injection molding | * MDF prints tooling and tests compatibility with injection molding of thermoplastics. * Quantify lifetime improvements of tooling over the incumbent tech. |
| *9 - 12* | * Application exploration: extend to rapid tooling for carbon fiber composite part manufacturing | * Validate compatibility of polySpectra printed tooling with composite layup processes |

**Use of Project Results**

polySpectra will use the results of this project to dramatically accelerate the commercialization of it’s high performance photopolymers. Specifically, the collaborative work on rapid tooling will enable us to test real world applications of advanced manufacturing with seasoned experts in the field. In many ways, our MDF collaborators will serve dual roles: as expert engineering consultants and as trial “customers” of polySpectra’s first product. By demonstrating highly impactful advanced manufacturing applications with the experts at MDF, we will address key engineering issues to accelerate our tech-to-market transition.

**Team**

*Raymond Weitekamp, PhD*

Raymond independently invented PLOMP and was awarded a $500k grant through Cyclotron Road to bring this project to LBL. In the last two years, he has mentored two postdocs, one bachelors-level researcher and four undergraduates on this project, in addition to initiating a number of new collaborations and initiating polySpectra’s customer discovery efforts. Raymond received his PhD in Chemistry from Caltech in 2015, working between the labs of Bob Grubbs and Harry Atwater, where he developed new materials chemistry and studied light-material interactions.

*Corinne Allen, PhD*

Corinne has a PhD in Chemistry and has been working on the synthesis and characterization of crystalline polymers for five years prior to joining this project. She has been working on this proposed project for the last twelve months and during this time she has learned the skills and created a workflow that can rapidly prototype both our resin and catalyst. Developing optimal photopolymer materials is a core part of this proposal and her past work has indicated that we will be successful in our proposed line of research.

*Aditya Balasubramanian, PhD*

Aditya has a PhD in Materials Science and has experience in innovative technical research involving novel UV curable resin development, characterization, and integration with lithographic systems. Completing and publishing scientific projects that require extensive thermomechanical characterization of materials, resin optimization for 3D lithography, and critical analysis of current lithographic materials has helped him develop technical abilities that can enable the successful completion of the proposed project goals.

**Cost Share**

polySpectra will have raised approximately $750,000 in private venture capital by the start date of this proposed work, and will be able to meet the cost share requirements of this grant through in-kind contributions of personnel, materials and equipment. We anticipate to be able to cost share Raymond at 20% time, with a base of \*\*\*, and 40% time for both Corinne and Aditya, at a base of \*\*\*, for a total of \*\*\*



1. Yan, X. & Gu, P. A review of rapid prototyping technologies and systems. *Comput. Des.* **28,** 307–318 (1996). [↑](#footnote-ref-1)
2. Thomas, D. & Gilbert, S. Cost Effectiveness of Additive Manufacturing. *NIST Spec. Publ. 1176* **1176,** (2014) [↑](#footnote-ref-2)
3. DOE/EE-0776. *Additive Manufacturing : Pursuing the Promise*. (2012). at <http://www1.eere.energy.gov/manufacturing/pdfs/additive\_manufacturing.pdf> [↑](#footnote-ref-3)
4. (a) Stratasys Ltd. PolyJet Materials Data Sheet. at [http://usglobalimages.stratasys.com/Main/Secure/Material Specs MS/PolyJet-Material-Specs/PolyjetMaterialsDataSheet-08-13.pdf?v=635376608792240585](http://usglobalimages.stratasys.com/Main/Secure/Material%20Specs%20MS/PolyJet-Material-Specs/PolyjetMaterialsDataSheet-08-13.pdf?v=635376608792240585) (b) 3D Systems Inc. Accura Stereolithography (SLA ) Material Selection Guide. *2015* at < http://www.3dsystems.com/files/downloads/3D-Systems-SLA-material-selection-guide-0813-USEN.pdf > [↑](#footnote-ref-4)