DPOC

DEFENSE PRECISION OPTICS CONSORTIUM

Tackling Challenges Facing the Defense Precision Optics Industry

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About the Author

Justin earned his PhD in Physics from Wake Forest University specializing in microscopy techniques for hemostasis, cancer, and regenerative medicine research. He then moved on to serve as a research scientist at Tesseract Sensors developing porous silicon rugate filters for anti-counterfeit applications and covert optical gunshot sensors for schools and civic buildings. While at St. Johns Optical Systems, he designed and managed a laboratory for developing low-cost MWIR focal plane arrays for defense and commercial applications.

As Advanced Product Manager at BEAM Engineering for Advanced Measurements Justin developed liquid crystal based diffractive optics and optical systems for applications ranging from non-mechanical beam steering to circular dichroism spectroscopy.

Justin is a subject matter expert in electro-optical systems engineering and has worked under several large defense programs including Army MAPS, DARPA WIRED, and DARPA POWER. He is an inventor on two patents, has written numerous publications, and has briefed members of Congress and ONR leadership on past research efforts.

About the Defense Precision Optics Consortium (DPOC)

DPOC is a member-based organization, committed to the evaluation of issues related to precision optics manufacturing technology development, performance standards implementation, supply-chain-issues mitigation, and education to ensure that the optics industrial base is responsive to the needs of the U.S. military. The goal is to catalyze the commercialization of new, mission-critical technologies. An advisory and review board made of industry and Department of Defense (DoD) representatives sets priorities and directs the execution of the AmeriCOM research agenda.

About The American Center for Optics Manufacturing

Charged by the U.S. DoD and its Industrial Base Analysis and Sustainment (IBAS) program, AmeriCOM is leveraging American ingenuity to forge new paths of prosperity for our nation's workforce while securing our advanced manufacturing industrial base. Working in concert with industrial, academic, nonprofit, and government partners, the AmeriCOM team of scientists, engineers, educators, and workforce development specialists are all dedicated to building up America's precision optics manufacturing industry.

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AmeriCOM CENTER FOR OPTICS MANUFACTURING

NSF IBAS Industrial Base Analysis and Sustainment Program

Tackling Challenges Facing the Defense Precision Optics Industry

The defense precision optics industry faces several significant challenges that impact its growth, development, and ability to meet increasing demands. Many of the most considerable challenges range from technical issues to market dynamics and to maintaining a skilled workforce. This paper explores these challenges and the work AmeriCOM has undertaken to solve them.

TABLE OF CONTENTS

Tackling Challenges Facing the Defense Precision Optics Industry

Manufacturing Technologies Challenges

The industrial base for optics manufacturing is developing increasingly complex and sophisticated optical systems driven by the wide-ranging and demanding needs of the U.S. armed forces. To maintain the technological edge over adversaries, optical manufacturers are tasked with pushing the boundaries of established and emerging technologies in optical fabrication. The demand for higher precision and enhanced functionality is activating the U.S. industrial base to develop cutting-edge manufacturing and metrology tools.

Just as aspheres replaced spherical optics in many applications, freeform optics are poised to revolutionize the industry once again, requiring more sophisticated machinery for grinding, polishing, and measuring. Automated 5-axis grinding and deterministic polishing methods allow for optics to meet customer's requests for tighter tolerances while innovations in ultra-precision machining such as diamond-turning processes have resulted in the achievement of sub-nanometer surface roughness on non-symmetric components. Yet, the boundaries are being pushed even further to introduce new capabilities into optical systems all the while using fewer components.

One area ripe with potential is the capability to integrate metasurfaces or diffractive surfaces onto freeform optics. Combining the diffractive effects of a metasurface with a freeform optic allows additional degrees of optical design freedom, enabling more complex optical systems with fewer components. Typically, the fabrication of subwavelength periodic structures that form a metasurface has only been possible on flat surfaces using lithographic processes such as electron beam lithography or nano-imprint lithography. Going forward, advanced manufacturing tools such as precision single-point diamond turning enable direct machining of a metasurface freeform. Many technical challenges remain, and active research is taking place to develop design rules for specifying these types of optics, metrology to measure their performance, and scaling to large sizes. AmeriCOM's optical manufacturing research facility has invested in precision diamond-turning tools to develop freeform optics combined with diffractive optics in an integrated small-format package.

Consistently producing optics of high quality for demanding applications also necessitates tight quality control over the substrate and coating materials. High-index glasses, engineered materials, and new ceramics are being developed and pushed to production floors. Advanced metrology methods are required to characterize these materials. A complete understanding of the properties of the materials and how they change under various environmental conditions is critical to inform model-based systems engineering efforts. AmeriCOM is working with industry and academic partners to develop metrology methods to characterize materials in challenging optical environments such as measuring the spectral emissivity of windows subject to dynamic and non-uniform heating or characterizing the change in optical properties and homogeneity of recycled optical materials.

Understanding and maintaining quality control over optical materials is especially important for high-energy laser applications. The highest precision manufacturing capabilities in the world won't produce a good optic if the homogeneity of substrate material or coating quality of an optic is flawed leading to sometimes catastrophic failures under a high-power laser. Currently, there is no set of standards for specifying high-energy optics commonly used across manufacturers. These challenges present an opportunity to develop new metrology methods that can predict laser damage thresholds over the entire surface of an optic before the damage occurs. Additionally, the maintainability of these systems must be considered. It is simply not cost-effective to require an ISO 5 cleanroom to maintain a fielded system. Instead, an in-situ monitoring system that detects the start of optical damage before the damage threatens the system is needed. An additional challenge is to incorporate the optics into a modular system architecture employing line-replaceable optical assembly units which would lead to higher system reliability and reduced maintenance costs. AmeriCOM is pursuing research to develop optical standards and metrology methods for high-energy laser damage monitoring and the impacts of contamination on damage thresholds.

By bringing together leading experts in industry, government, and academia, through the AmeriCOM Defense Precision Consortium (DPOC) the precision optics industrial base is poised to identify key obstacles and work collaboratively to develop innovative solutions. Those who embrace these technical challenges as opportunities for innovation will succeed in leading the industry in the face of an ever-evolving market.

Market Dynamics Challenges

In addition to manufacturing technologies challenges, attention must be paid to market dynamics that are at play in the defense precision optics industry, most notably from global competition and supply chain disruptions.

SPIE reports the global optics and photonics industry reached $368 billion in 2022 [1]. About two-thirds of the optics and photonics global market is centered in Asia-headquartered firms, particularly in Japan, China, Korea, and Taiwan. The exodus of manufacturing from the United States to other countries, particularly those with low labor costs, has been well documented. Optical component manufacturing has largely been dominated by Asia's cost-effective production capabilities. Optics and photonics company revenues in the U.S. and Japan have remained relatively flat over the last decade compared to China, Korea, and especially Taiwan, which has exhibited approximately 120 percent revenue growth between 2020 and 2022.

Despite the loss of high-volume optical component manufacturing abroad, the U.S. optics industry has remained competitive in the realm of precision optical components, high-quality optical assemblies, and integrated optical systems. The U.S. precision optics manufacturing sector has leveraged its technical prowess to implement automation technologies including robotics, AI, and advanced metrology to ensure superior quality and consistency in products. Automation has allowed U.S. precision optics manufacturers to mitigate labor shortages and maintain an advantage over Asian manufacturing where the emphasis has been on labor-intensive processes that are not conducive to manufacturing precision optics with consistent quality. This technological edge has in part been bolstered by the U.S. brain gain. For example, the MarcoPolo Global AI Talent Tracker, which tracks AI researchers, reported that in 2019 88% of Chinese-born PhDs in artificial intelligence end up working in the U.S. and nearly all Indian AI researchers opted to pursue opportunities abroad [2]. Historically the causes of this trend have been that the U.S. can pay higher salaries and American academic institutions are perceived as superior in terms of prestige and quality. However, these trends are not expected to continue. In recent years, China has begun directing billions of dollars in funding to attract and retain talent across high-tech industries. The effects of these efforts are starting to be seen in the AI industry where just 42% of AI researchers in the U.S. in 2022 are foreign nationals, down 13 percentage points from 2019 meaning more top-tier talent are staying put in their home countries [2].

Another reason the U.S. precision optics industry has remained competitive is due to significant funding from the defense sector. Many defense systems including targeting systems, infrared search and track, space-based systems, and high-energy laser weapons rely on precision optics. The U.S. continues to spend significantly more on defense compared to any other nation. The U.S. Congressional Budget Office proposed a defense budget of $842 billion for 2024, which would remain unchanged until 2028 when adjusted for inflation. Meanwhile, over the last five years, China has steadily increased its defense budget by approximately 7% per year on average. You can be sure that much of that funding is going to China's defense industrial base including the precision optics industry.

What all this means is that the U.S. precision optics manufacturing industry must be able to provide a product that delivers superior value in an environment where global competition is not only directly price-competitive but is also investing heavily in developing higher-quality goods. AmeriCOM is focused on this very issue by working with domestic industry partners to develop models and algorithms that enable full-aperture deterministic polishing using machine learning. The goal of the effort is to allow CNC polishing tools to automatically adapt to changes in tool wear, environmental factors, slurry composition, and variables that currently require the attention of a technician to monitor. New CNC tools with this capability can enhance the productivity of a single technician, thus reducing labor costs.

Another major market challenge faced by the U.S. defense optics industrial base is supply chain disruptions. The COVID-19 pandemic, trade sanctions, and other geopolitical and economic concerns have highlighted supply chain vulnerabilities even as the precision optics industry has continued to grow. The war in Ukraine has shown the criticality of a robust defense industrial base and its effects on national security while also punctuating its vulnerabilities when critical optical materials are in short supply. Thin-film coating materials used for laser optics and optical filters such as hafnium have increased in price by more than 150% since 2022 [3]. Germanium used to make infrared optics has increased in price by more than 70% over the same period [3].

Germanium is of particular concern for the defense precision optics industry. Its high index, good long-wave infrared transmission, low optical dispersion, and compatibility with diamond-like carbon coatings make it ideal for infrared optics, especially in defense imaging systems found on tanks, rotorcraft, and fixed-wing aircraft. Germanium is also found in many of the chalcogenide glasses and is used in solar panels and fiber optics. Despite its widespread use, China produces 60% of the world's germanium according to the Critical Raw Materials Alliance (CRMA).

As of August 1, 2023, China instituted export restrictions on germanium causing European and North American countries to scramble for alternative sources. While approximately 30% of the germanium in the U.S. is from recycled sources, this is not enough to keep up with demand resulting in soaring prices and lead times for germanium optics.

The Department of Defense is aware of critical shortages and is taking steps to support supply chain resiliency. Legislative proposals to procure additional materials for the national stockpile and to create a separate reserve of strategic rare earth minerals have been submitted to Congress. In recent years, the Department of Energy and the Department of Defense have funded several programs to develop new sources of critical minerals or make alternative sources of critical minerals more economically feasible. Specific to germanium optics, research is ongoing to reduce the amount of germanium in optical systems, improve recycling processes, and find germanium alternatives. AmeriCOM is specifically funding and participating in research related to large alternative material infrared optics, photonic materials manufacturing assessments, and alternative sources and refinement of germanium.

Workforce Development Challenges

Like most advanced manufacturing sectors, the defense precision optics industry also faces a workforce challenge. With the rising demand for precision optical components, there is a corresponding need for skilled optics technicians. As the demand for these technicians is increasing, the size of this skilled workforce is decreasing, particularly as experienced workers retire. Currently, Optica lists nearly 1400 open positions in the optics industry [4] while Indeed lists over 1000 job openings when searching for optics manufacturing technicians [5].

It has been estimated that for every optics engineer focused on manufacturing innovation, a minimum of 10 optics technicians are needed to bring the innovation to market. The existing training capacity within the U.S. community college system is inadequate to train replacement workers or to grow the workforce to support our future needs. This directly affects our nation’s ability to advance the industry overall. Designs of complex, modern optical systems such as directed energy systems and hypersonic missiles, are determined and limited by manufacturing capabilities including the availability of a skilled workforce. AmeriCOM has identified four foundational issues that currently contribute to the shortfall of skilled precision optics technicians.

The first issue is the pool of skilled optics technicians is aging out of the workforce with few pipelines of skilled workers to replenish it. As a result, the industry must engage and attract a larger proportion of high school students along with adult workers and

workers from other industries. Despite the pervasiveness of optics in our everyday lives, high school students are largely unaware of the optics manufacturing industry, and we must do a better job of marketing career opportunities.

The second issue is that, over the last four decades, existing precision optics manufacturing jobs have moved offshore, thus eroding the education, training, and recruitment pipelines for skilled industrial workers. Workforce requirements have decoupled from the schools that traditionally trained and educated future manufacturing workers as education shifted toward supporting the service industry. Today's students are not exposed to career options in precision optics manufacturing, and this has a negative impact on the number of future skilled workers entering the career pipeline.

Cultural perceptions of education have been changing over recent decades, with families placing a higher value on traditional four-year college degrees over skilled trade programs, further contributing to the diminishment of the pipeline of skilled workers. Jobber's recently released *Blue Collar Report* surveyed 1,000 U.S. 18-20-year-olds and found that 74% of respondents say there's a stigma associated with going to a vocational school over a traditional four-year college or university. Additionally, 79% of respondents say their parents want them to pursue a college education after high school and only 5% say the same about vocational school [6]. The U.S. service-based economy of today places reduced emphasis and value on manufacturing as both an essential capability and a professional, rewarding career path for American workers. As a result, cultural dispositions in the U.S. do not favor early decisions to prepare for and enter manufacturing career paths, further complicating the supply side of the problem.

A fourth issue is one that affects community colleges, where the majority of the nation's technician training programs take place. These institutions struggle with the high cost of workforce development programs. Community college tuition rates are often set by their states at a level below what is needed to cover Career and Technical Education (CTE) program costs including pay for instructors. These schools also lack the investment capital needed to set up advanced manufacturing skills training facilities, and they do not have sufficient operations and maintenance funding to sustain training. While federal government investment helps reduce the risks inherent in training program development, community colleges must continue to develop and strengthen industry relationships and seek additional grant funding from a range of governmental and philanthropic sources to help address these ongoing resource issues.

These issues can be addressed by partnerships with industry, education, nonprofit, and government sectors, and is the basis of the optics ecosystem model that AmeriCOM is building in key areas around the country, where there is a concentration of optics and photonics manufacturing companies, Stakeholders in these ecosystems identify the issues that limit defense precision optics manufacturing and harness collective resources in order to set up training labs at community college facilities. As part of this, AmeriCOM launched and manages a marketing and outreach program to raise awareness of optics career paths and drive enrollments into the new optics technician training programs.

Turning Challenges into Opportunities

As outlined above, the defense precision optics industrial base faces significant challenges. AmeriCOM's mission is focused on developing advanced optics manufacturing technologies to support scalable manufacturing, transitioning mission-critical precision optics technologies from research to sustainable manufacturing operations, and developing workforce training programs to support the nation's precision optics industry. Its goal is to work with industrial, government, and academic partners to find innovative solutions to each of the presented challenges.

To that end, AmeriCOM Defense Precision Optics Consortium (DPOC) provides its members access to emerging research in optics manufacturing technologies, access to optics manufacturing and metrology user facilities, and a growing technician talent pool. The AmeriCOM user facility in Fairport, NY provides a non-competitive environment and state-of-the-art optical manufacturing and metrology tools as a resource for the precision optics industry for prototype development, collaborative research, and continuing education through short courses and webinars.

It is currently free to join DPOC and more information can be found at https://americom.org/optics-manufacturing-technologies-research/.

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