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ABSTRACT

In thirty-five years, more than thirty optics-related companies have been established in the small Rocky Mountain town of Bozeman, Montana, USA. This situation offers a rare opportunity to examine the parallel growth of optics education and industry in a location that until recently was home to very few, if any, high-technology companies. The growth of optics education and research at Montana State University (MSU) in Bozeman was both a cause and a result of the parallel growth of surrounding optics-related companies. The earliest academic optics activities at MSU were in both applied optical measurements and basic optical sciences, especially laser crystal spectroscopy and laser physics, and our first optics companies were in similar fields. In fact, one of the first companies was started by an MSU graduate who grew the crystal for the world's first ruby laser built by Dr. Theodore Maiman. After the start of this growth in the 1980s, the next several decades brought synergistic broadening of optics activities to a wide range of applications, from remote sensing to medical imaging. This paper outlines the events that initiated this development and the ongoing activities that continue to promote this synergistic growth of optics in both academia and industry.

Keywords: Optics education, optics research, optics industry, economic development

1. INTRODUCTION

Until very recently, graduates of Montana State University interested in optics and photonics had little choice but to move out of Montana to seek employment in other regions, typically in big cities with a large number of high-technology companies. However, today's students are finding increasing opportunities for employment in the rapidly growing optics and photonics industry in and around Bozeman, Montana. Similar growth is occurring in optics and photonics research programs at Montana State University (MSU) and the university and industry are growing in a synergistic pattern. This growth began in the 1980s and continues today.

This growth is particularly notable because it is occurring in a small town in Montana, a state that has historically been better known for cattle ranching, copper and coal mining, and hunting than for any kind of modern technology. Straddling the Rocky Mountains in the northwestern United States and extending eastward into the Great Plains, Montana has the fourth-largest area but the third-lowest population density of the 50 states. Its largest city has only approximately 100,000 people and Bozeman is only the third- or fourth-largest city in the state (its population was listed in the 2010 census as 37,280). Prior to the Internet age, it was nearly impossible to run a competitive technology-based company or university research group in this relatively remote location. However, that has changed dramatically since the parallel establishment in the 1980s of optics-related university research and companies in Bozeman. This paper summarizes some of the key events in this parallel development and identifies the key elements that have allowed this somewhat unlikely development to continue.

2. BEGINNINGS OF THE OPTICS INDUSTRY IN MONTANA

The growth of optics-related companies in Montana is shown graphically in the timeline of Figure 1, which shows the year of establishment of each optics-related company in the area. Interviews with the founders[1,2] indicated that these first optics companies came to Bozeman for a combination of the outstanding quality of life and the reputable engineering and science programs at Montana State University. Orionics Inc. arrived in 1980 after Roger Robichaud left Los Alamos National Lab in New Mexico to manufacture optical fiber splicing and test equipment. He learned of Bozeman from his engineer, who was an MSU graduate. In 1981, MSU physics graduate Ed Teppo returned to Montana from the U.S. Navy facility at China Lake, California and founded Big Sky Laser Technologies to manufacture rugged solid-state lasers. In 1984, Toomay-Mathis and Associates (TMA) was established by a pair of retired Air Force generals and Dr.

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John Stover, a young faculty member in the MSU Electrical Engineering Department, to develop scatterometers for measuring surface roughness on precision optical components. ILX Lightwave was started in 1986 by Dr. Larry Johnson, who discovered Bozeman when he was invited to use Orionics equipment at their Bozeman facility while they built a system for his employer in Minnesota. The final two optics-related companies arriving in the 1980s were Scientific Materials Corp. and Lattice Materials Corp., both beginning operations in 1989. Lattice Materials Corp. was founded by John Tengelsen as a supplier of infrared optical materials and components. Scientific Materials was founded by Ralph Hutcheson, an MSU mechanical engineering graduate who earlier at Union Carbide Corp. had grown the ruby crystal used in the world's first laser, invented by Dr. Ted Maiman in 1960. Orionics was purchased by Ametek in 1985 and ended operations in 1987. By 1990, the five remaining optics companies in Bozeman were beginning to provide the first signs of what the future could hold, and the university was making some wise moves that would help create that future.

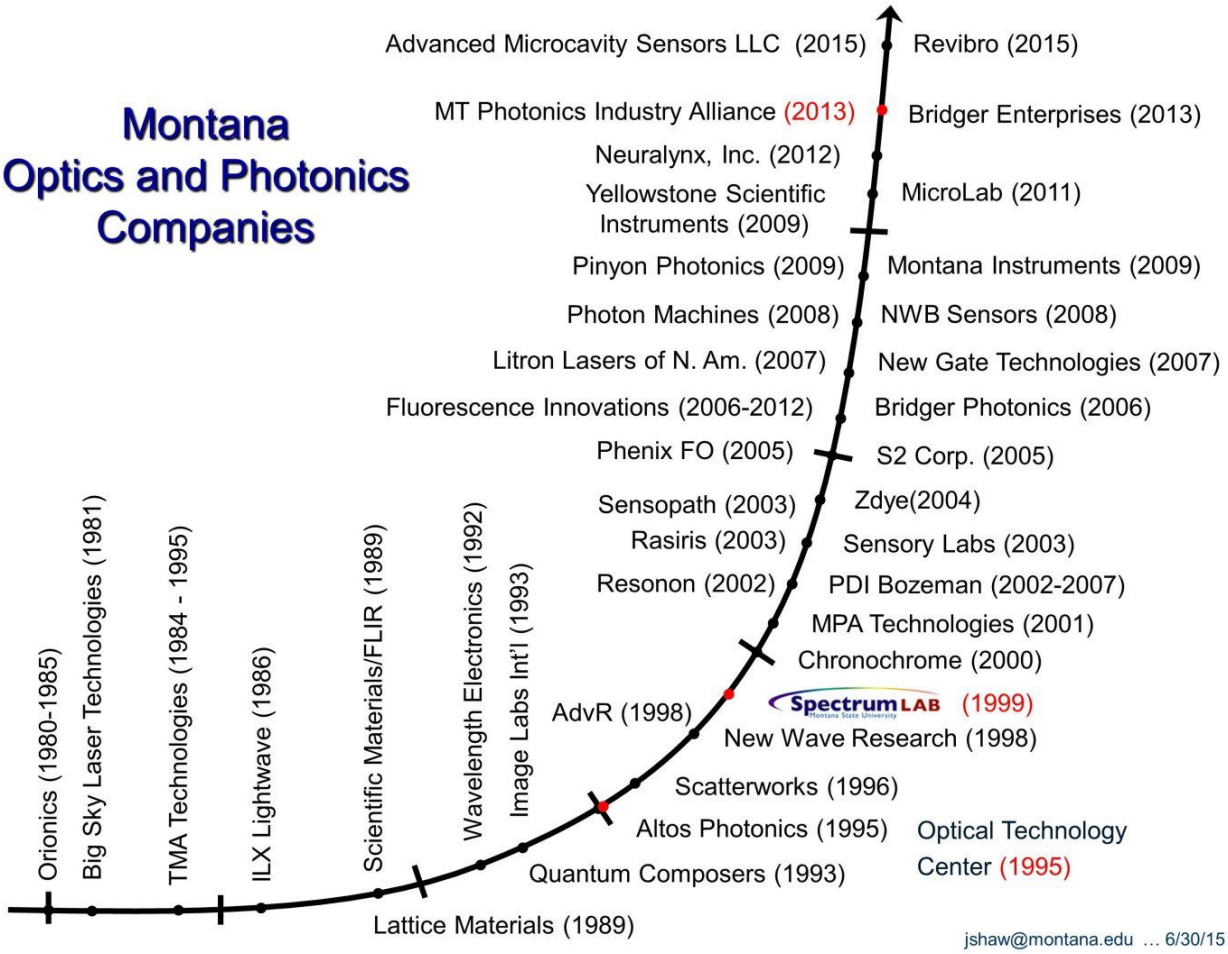

Figure 1. Timeline of companies and optics organizations established in Montana.

3. BEGINNINGS OF OPTICS RESEARCH AND EDUCATION IN MONTANA

Although the first few companies were established in a seemingly chaos-driven, rapid series of unpredictable events, the university was involved directly or indirectly from the very beginning. The most direct early university involvement was with the optical scatterometry company TMA & Associates. Somewhat ironically, the same week he was awarded tenure in the MSU Electrical Engineering (EE) Department, Dr. John Stover resigned his faculty position to devote his efforts to the new company. However, even after leaving the university he continued to teach an electro-optics course in the EE Department and to collaborate with Dr. Fred Cady who remained at MSU. Together they recruited the best students to work at the company and at least one graduate thesis was completed as part of this mid-1980s collaboration.

Before joining TMA, John Stover called Dr. John Carlsten at Los Alamos National Lab (LANL) to encourage him to apply for an open faculty position in the MSU Physics Department. Dr. Carlsten arrived at MSU in 1984 with a truckload of optical equipment supplied by LANL to help establish a collaborative laser physics program. Soon after arriving in Montana, John Carlsten happened to meet Larry Johnson from ILX Lightwave Corp. while sharing a lunch table at the local ski hill. Larry's company soon began funding a small research effort in John's lab to study stability and noise performance of diode lasers. Not much later, another collaborative relationship grew up between the newly established laser crystal company Scientific Materials Inc. and Dr. Rufus Cone, a laser spectroscopist in the MSU Physics Department. In fact, this opportunity for collaboration was one reason behind the choice of Bozeman as the location for this new company, which needed exactly the expertise provided by Dr. Cone.

The fledgling partnerships established in the 1980s easily could have stagnated or withered instead of continuing to grow and spin off more companies, but instead there were several key investments of time, effort, and funding by the university and by the state. The most important characteristic of these investments was that they were designed to benefit a larger group than just the individual people involved. These unselfish efforts resulted in the growth of a broader and more diverse optics program than could have been possible with only single-investigator research efforts.

In 1990 and 1991, two people involved with growing the research enterprise at MSU, Vice-President for Research Bob Swenson and Plant Sciences Professor Gary Strobel, took notice of the fledgling optics collaborations and encouraged John Carlsten to build on them by hiring additional optics faculty and establishing an optics center. Dr. Strobel was leading an effort to invigorate MSU research through the National Science Foundation's Experimental Program to Stimulate Competitive Research (EPSCoR) and this is the program through which John Carlsten submitted an important proposal in 1992.[3] This proposal was entitled "Optical Science and Laser Technology" and had the goal of forming a "group in optical science and laser technology at Montana State University" for the "development of nationally competitive optical programs that have the possibility of leading to technology transfer to the local optical industry in Bozeman and the state." The five-year proposal requested $1,033,453 from the NSF and committed an additional $981,250 from the Montana Science and Technology Alliance (MSTA, created by the Montana Legislature in 1989) and $867,516 from MSU, for a total budget of $2,882,219. The NSF funds were used for faculty summer salary, postdoctoral researcher salary, and graduate student stipends, along with associated indirect costs. The MSTA funds were used for equipment, travel, supplies and associated indirect costs, while the MSU funds were used for new faculty salary, benefits, a small amount of equipment, supplies, travel, and associated indirect costs. The primary lesson to learn from these details is that there was an essentially equal three-way investment made by Montana State University, the State of Montana, and the National Science Foundation during the period 1993 – 1998.

Another key lesson to be learned from this proposal is the long-term value of an investment in faculty with strategically chosen research expertise. The proposal provided funding to strengthen the research capabilities of four faculty members in three university departments, focusing on activities that could benefit local industry (see Table 1), but it accomplished much more by also coordinating the university-funded hire of at least one additional faculty member in each of these three departments. In fact, these efforts and related funding eventually led to the hiring of even more faculty members across campus. While the 1992 NSF proposal led directly to the hiring of Aleksander Rebane in Physics, David Singel in Chemistry, and David Dickensheets and Chris Yakymyshyn in Electrical and Computer Engineering (ECE), it later led indirectly to further hires so that as of the writing of this manuscript MSU has eighteen tenure-track faculty, at least eight research faculty or professional research staff, and several dozen students working on optics-related research.

The importance of the balance across academic disciplines in these hires cannot be overstated: the strategically invested funding was used to hire and establish new faculty covering the spectrum of basic optical science to optical engineering and applications. This diversity has resulted in numerous new opportunities for collaboration, both among the optics faculty and with faculty in other departments (e.g., optical remote sensing with Agriculture and Land Resources and Environmental Sciences, bio-optical imaging with the Center for Biofilm Engineering, etc.).

In August 1992, a workshop was held at Montana State University to explore strategies and opportunities for university-industry collaboration in optics. This began the tradition of an annual conference to review optics activities on campus and in local industry. This tradition continues today and is widely recognized as one of our most important activities because of the continual opportunities these conferences present for establishing and maintaining personal relationships. Students, faculty, and local business leaders spend time together in the same room, getting to know each other and having discussions that often launch new collaborations. Furthermore, the conferences and frequent colloquia provide opportunities for current students to meet and listen to previous students and other company leaders tell how they started and are running their companies. This instills in students an entrepreneurial spirit that helps maintain the continuing

growth of the local industry. The annual conference tradition continues today under the direction of the Optical Technology Center (OpTeC), formally designated as an interdisciplinary center by the Montana Board of Regents in 1995 with John Carlsten as Director (John led the formation of the center and served as director until 1997, Lee Spangler was director from 1997 to 2004, and Joseph Shaw became director in 2004 and continues in that position as of the writing of this paper in 2015).[4] Figure 2 shows a sampling of photographs from prior conferences.[5]

Table 1. Faculty research activities funded by the 1992 NSF proposal that launched the MSU optics program

Faculty	Department	Research Activity	Relevant Local Company
John Carlsten	Physics	Diode laser frequency stability	ILX Lightwave
Rufus Cone	Physics	Rare-earth-activated materials for solid-state lasers	Scientific Materials
Lee Spangler	Chemistry	Multi-dimensional spectroscopy of laser crystals	Scientific Materials and Big Sky Laser
Fred Cady	ECE	Computer-generated hologram reflectance standards	TMA Technologies

Figure 2. Photographs of various groups of students, faculty, and business leaders during some of the annual Optical Technology Center conferences held at Montana State University.

MSU optics faculty remain in traditional departments, but the Optical Technology Center serves as an umbrella-like organization, bringing together students and faculty doing optics-related research and promoting optics education, research, and technology transfer into local industry. In 2013, the Montana Photonics Industry Alliance[6] (MPIA) was created for the larger purpose of promoting policies to support the photonics industry and for helping to recruit

employees into local companies and students into MSU optics programs. The founding MPIA President was Dr. Larry Johnson, who had recently sold his company ILX Lightwave to Newport Corporation. Together, OpTeC and MPIA provide valuable communication and interconnections among the university, companies, and city and state government.

There has been steady growth of optics in industry and at the university since the establishment of the first optics companies and university projects. Many of these companies were started by MSU graduates, often after they explored opportunities elsewhere and then returned to Montana. Some companies have licensed MSU technologies, others have collaborated with MSU, and others have remained independent. An important lesson to note in all of this is that nearly all the MSU graduates who started optics and photonics companies held Ph.D. or master's degrees. This highlights the crucial role of graduate education and research, not only for creating new technologies that can be licensed or adopted by companies, but also for training students with the advanced skills required to establish and operate a high-technology-based company.

Although the majority of company founders have been Ph.D. graduates, the growing companies now need a broader range of education. Therefore, in recent years MSU has been increasing the educational offerings for master's degree and undergraduate students, as shown in Table 2. The optics and photonics courses available to students at the time of this writing are listed in Table 3 (there is currently in development a photonics technician degree program at Gallatin College, a two-year community college affiliated with MSU, which is not included in the tables). Finally, Table 4 lists the primary optics and photonics research activities being undertaken at MSU.

Table 2. Degree options for students to study optics and photonics at Montana State University as of Fall 2015.

Degree	Notes
Ph.D. in a departmental discipline	Physics, ECE, or Chemistry & Biochemistry
Ph.D. in Optics and Photonics	To be proposed soon as an interdisciplinary degree for students in Physics, ECE, or Chemistry and Biochemistry
M.S. in Optics and Photonics	Approved in 2014 as an interdisciplinary degree for students in Physics, ECE, or Chemistry and Biochemistry
M.S. in a departmental discipline	Physics or ECE
Undergraduate Minor in Optics and Photonics	Available to all MSU students (primarily from the Physics, ECE, and Chemistry & Biochemistry Departments)

Table 3. Optics and photonics classes available at MSU as of Fall 2015.

EELE 408 Photovoltaic Systems	EELE 482 Electro-Optical Systems
EELE 484 & 584 Laser Engineering	EELE 505 MEMS Sensors and Actuators
EELE 538 Advanced Topics in Electromagnetics & Optics	EELE 581 Fourier Optics and Imaging Theory
EELE 481 & 582 Optical Design	EELE 583 Remote Sensing Systems
PHSX 253 Physics of Photography	PHSX 305 The Art and Science of Holography
PHSX 427 Advanced Optics	PHSX 437 Laser Applications
PHSX 444 Advanced Physics Lab	PHSX 531 Nonlinear Optics and Spectroscopy
CHMY 527 Analytical Optical Spectroscopy	CHMY 560 Symmetry, Orbitals, and Spectroscopy
OPTI 591 Special Topics	OPTI 592 Independent Study
OPTI 590 Master's Thesis	OPTI 594 Optics and Photonics Seminar

Table 4. Primary optics and photonics research activities at MSU as of Fall 2015.

Design, calibration, and applications of radiometric and polarimetric imaging systems	Design, calibration, and applications of lidar systems for remote sensing of the atmosphere and lake ecology
Design, calibration, and applications of spectral imaging systems for precision agriculture	Development of MEMS and nano-optical components and systems for focus control, biological imaging, and spectro-polarimetric imaging
Design of biomedical imaging and spectroscopic systems using MEMS optical components	Micro-cavity sensors for hyperspectral imaging
Synthetic-Aperture LADAR	Compressive laser ranging
Coherent LADAR and atmospheric turbulence studies	Spectral hole burning
Photonic-enabled wideband signal processing	Spectroscopy of laser materials
Design and applications of hyperspectral imagers for proteomics studies	Optical studies of interface chemistry
Photovoltaic materials	Nanoscale photonics and photochemistry
Ultrafast laser spectroscopy	DNA photophysics and photochemistry
Nonlinear optical materials	Nonlinear optical spectroscopy
Machine vision and statistical image processing	Computational vision science and neuroscience
Nonlinear optics and photodynamic therapy	Laser physics and engineering
Two-photon absorption for medical imaging	Organic and hybrid organic/nanoparticle photonic materials

Finally, it is important to note the added value that has been created as our community has become home to a cluster of companies. This added value is manifest in at least three ways. First, employees can move from one company to another as demand increases in one place and decreases in another. Second, when larger out-of-state companies buy our existing companies, they now tend to leave them in Montana because of the vitality of the local optics and photonics community (for example, FLIR Systems, Inc. purchased Scientific Materials in 2005 and Newport Corp. purchased ILX Lightwave in 2011, and both deals resulted in the companies not only remaining in Montana, but also growing beyond their pre-purchase size). Third, other companies have seen what is going on in Montana and have chosen to create an office here. The number of companies is continuing to increase, as are the number and variety of exciting applications of optical science and technology being developed in a small Montana town where only three decades ago this was all unexpected.

4. CONCLUSION

A new, dynamic center of activity in optics and photonics is developing in Bozeman, Montana - a small university town in southwestern Montana in the northwestern United States. Over a period of thirty-five years, more than thirty optics and photonics companies have been established in Bozeman and similar numbers of faculty and research staff have been hired at the university to conduct vigorous research programs. Since the beginning and continuing today, there has been a very collegial relationship between the university and local industry, with many leaders and employees at local companies being graduates of the Montana State University optics programs. The growth has occurred in a parallel and synergistic fashion at the university and in local industry. A careful, retrospective examination of this growth, including interviews with some of the principal people involved in this growth, has identified the following critical elements that must be considered if one wishes to understand or replicate this process.

- **Desirable location** - It all started for us with a desirable location with local ski resorts and Yellowstone National Park in our backyard, but it is important to remember that "desirable" simply means that there is a broad base of people who are drawn to the location strongly enough that they are motivated to create their own job instead of just finding one in an arbitrary location.

- **Research university** – Creating and sustaining this kind of partnership requires a local university with a serious commitment to research. In the early 1980s MSU was a teaching-intensive college with only a few pockets of strong research activity, but vigorous effort coupled with some strategic investments by both state and university administrators helped MSU become a top-tier research university. In other words, you cannot create what we have in Montana just by teaching the right classes.

- **Excellent people willing to take a chance and work together** – This is closely related to the first bullet ('desirable location'), as there must be something that is worth the chance taken by excellent people. The right kind of people may be hard to find, but it is critical to search for those who have the proper mixture of intelligence, creativity, energy, self-motivation, and community spirit (the last one is often the hardest to find in highly driven faculty candidates, but it is vital that the faculty in this kind of effort have a commitment to something bigger than their own research program or glory). In our case, we recognize the huge positive impacts made by smart people with pioneering spirits who came to Montana to open a company or to establish their university career, despite being good enough to go to much more established places or more prestigious universities.

- **University-industry partnerships** – These simply do not happen automatically or even easily. As Ralph Hutcheson explained in our interview with him, at MSU he found the expertise he needed but could not afford to hire as full-time employees when he founded Scientific Materials Corp., but it took at least five years for everyone to learn to communicate and collaborate effectively. Not only were policy changes needed at the university, but there also was time required for the university people to realize that industry people were not bad and vice versa. There must be genuine willingness to do some hard non-research work to enable collaborative research.

- **Pro-industry attitudes and actions at the university** – This is closely related to the previous bullet, but it is of such critical importance that it is listed by itself here. Especially in science departments where basic research reigns supreme, it is quite common to find faculty who feel that industry is a lesser destination for their graduate students relative to academia. If a professor suggests that his or her best Ph.D. graduates can "do better" or "reach higher" by landing a university faculty position instead of by establishing an optics company or taking a position with a local optics company, those students are quite unlikely to pursue the latter paths. At MSU our optics faculty members in all departments are engaged with research that sometimes has a connection with local industry. That, along with the relationships that are built and sustained through our annual meeting and other activities, sends a powerful message to our students that we value industry and what is done there. Consequently, a significant fraction of our graduates (even at the Ph.D. level) find their way into companies.

- **Recognition of unique roles of academia and industry** – Effective collaboration, technology transfer, or even industry-guided curriculum development requires both sides to clearly recognize and appreciate the very different roles naturally filled by academia and industry. Academia is best at educating students and conducting research, while companies are best at refining research results and turning them into commercial products.

- **Personal relationships** – Especially when growing from a very small number of companies and faculty, as we did, it is vital to create regular opportunities for students, faculty, and industry leaders to build personal relationships. This pays dividends at all levels, with students knowing who to talk to about future jobs and business leaders knowing who to talk to for consulting expertise or future partnerships. We accomplish these things through our annual meeting and frequent colloquium talks (to which industry people are invited and for whom provisions are made such as pre-paid university parking, etc.).

- **Strategic investment** – Finally, none of this works without money and other resources. In Montana, there were strategic investments of funding made by the state legislature, the university, and the National Science Foundation (in addition to agencies such as NASA, who were significant sponsors of high-quality laser crystal development, etc.). For example, our all-important 1992 NSF proposal was enabled by matching funds provided by the state legislature through the MSTA, matching funds provided by MSU for strategic faculty hires, and by unselfish investments of time and effort by faculty and administrators who worked together to build something bigger than their own research program.

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