Commercialization Plan

Small Business name: **Incom Inc.**	Principal Investigator: **Mr. Michael R Foley** **Telephone: 508-909-2320** **E-mail:** mrf@Incomusa.com
Topic 24 - Nuclear Physics Instrumentation, Detection Systems and Techniques , Subtopic a) Advances in Detector and Spectrometer Technology DOE Opportunity # DE-FOA-0001366 CFDA Number: 81.049	
Application Type: Phase I SBIR	
Project Title: **"**Development of Gen-II LAPPD^{TM} Systems For Nuclear Physics Experiments**"**	

Incom Inc. estimates sales revenues of $25 million dollars during the first 10 years of commercialization. Incom has no immediate plans to license its technology to others.

A) Market Opportunity

1. Product or Service – The Large Area Picosecond Photo Detector (LAPPD^{TM}**)** is a Micro-Channel Plate (MCP)-based photon detector capable of imaging at high spatial and temporal resolution in an ultra-high-vacuum (UHV) hermetic package with an active area of 400 square centimeters. The basic technology allows optimization over a wide range of design parameters to meet the specific needs of a wide range of commercial and scientific applications, optimizing for temporal or spatial resolution, high or low counting rates, and areal-coverage and packaging constraints. The LAPPD^{TM} development was made possible by the development of 20-cm-square glass capillary substrates, functionalized with Atomic Layer Deposition, a size that would be very difficult to fabricate by the conventional solid-core etching process. Two additional key technologies were also developed in parallel, the integration of high-bandwidth micro-strip anodes into the LAPPD^{TM} hermetic package, and the development of 10-15 Giga-sample/sec low-power multi-channel integrated circuits for large-scale high-resolution electronics systems used in large scientific detectors and in medical imaging. LAPPD^{TM} prototypes have been shown to achieve gains greater than 10^7 non-uniformity < 15%, a time response for single photons of better than 50 ps (less than 10 ps for charged particles), and a spatial resolution of 0.5 mm × 0.5 mm for single-photon detection over an area of 400 cm^2.

Incom's early participation in LAPPD^{TM} development, was the result of being able to manufacture large area fine-grain capillary array substrates, gang sliced from large blocks of hollow core capillary, which when ALD coated to produce MCPs, have the potential to cover large areas, at an affordable cost. In 2013, Incom was awarded Phase I and II SBIR Technology Transfer Opportunity funding by the Department of Energy (DOE) with the goal of establishing infrastructure to demonstrate the capability for LAPPD^{TM} pilot production. Since then Incom has constructed a pilot-scale facility to address all facets of LAPPD^{TM} manufacture, including fabrication of the 20 cm glass capillary substrates, the ALD coating equipment to convert GCAs to MCPs, and the equipment needed to assemble the detector in UHV, and perform QC for production. In addition Incom has assembled a team experienced in high-speed signal processing, ALD, photocathodes, electronics and testing of MCP-based photodetectors, and applications of photodetectors in the commercial sector.

Commercialization Plan

Accurate particle identification across a wide energy/momentum range is critical for meeting the physics goals of several of the current and coming generations of DOE-supported Nuclear Physics experiments, with the proposed Electron-Ion Collider generating particularly demanding requirements. Precise event timing, at the 10 picosecond level or better, holds promise for significantly advancing the state-of-the-art of time-of-flight for particle identification and the association of particle tracks with vertices. In addition to precise spatial and temporal resolution and affordability, use in high-rate environments such as those at colliders or near reactors will require spatial segmentation with high rate capability. This proposed Phase I program will result in the development of a second-generation, Gen II LAPPD^{TM} which incorporates a pixelated anode (`pads') for high occupancies and rates The Gen II LAPPD^{TM} program also includes developing a pixelated pin-free anode for a high-purity ceramic body designed for low cost volume production. The Gen II LAPPD^{TM} will have fewer parts, be easier to assemble and seal, and so should have a higher production yield and therefore be less expensive to produce. The ceramic package will also have lower intrinsic radioactivity; be physically stronger, and have higher RF bandwidth. The design concept will support both a wide variety of application-specific pixel patterns as well as microstrip readout

Low cost and improved manufacturability – The proposed program builds upon the experience gained through the development of "all glass" LAPPD^{TM} which is currently the focus of a DOE-funded Technology Transfer Opportunity (TTO) program to enable pilot production at Incom Inc. Under that program, a complete tile pilot production facility has been established at Incom. Substantial simplifications to the hermetic package design and improvements in the manufacturability of the-all glass LAPPD^{TM} have been accomplished. . Initial detector integration and sealing trials are now underway at Incom, with the goal of demonstrating pilot production of LAPPD^{TM}, before TTO program completion in April 2016. Every step of the fabrication process for LAPPD^{TM} has been individually demonstrated, including the 'top seal' of the window to the sidewall. The major issue that remains is demonstration of manufacturability, which is a question of tolerances, the number of process steps, yield per step and reproducibility. The proposed Gen II LAPPD^{TM} program incorporates ceramic materials, with rough tolerances machined in the green unfired state for lower costs, and final finished in the ceramic state; this will provide the precision internal stack-up required for top window sealing, while also providing increased strength and toughness. With these simplifications and their resultant lower unit costs, the proposed Gen-II package will incorporate a pin-free pixelated anode significantly improving device performance at high distributed-photon event rates.

[Inside out approach – The proposed Gen II LAPPD^{TM} program will provide a proof-of-concept demonstration, using both glass and ceramic-tile components, of capacitive coupling through the bottom plate using pin-free pixelated anode pads. This design will eliminate expensive and leak-prone brazed metallic feedthrough pins commonly used with traditional ceramic photodetector packages.

The "inside-out approach" (more fully described in the Narrative section) relies on capacitive coupling of signals through the vacuum package. It is based on the nature of the spatio-temporal information content of the detected signals which consists almost entirely of their higher-frequency components (spatially and temporally). In the readout process, the mapped amplitudes of electromagnetic-field modes are changed minimally when the orientation of the anode is changed such that the ground plane is inside the vacuum package and the pattern is outside. This simple design change results in a number of important benefits:

1. Reduced risk of vacuum leaks by minimizing electrical feed-throughs in the vacuum package,
2. Improved signal bandwidth,
3. Ability to modify the anode pattern without changing the detector itself.
4. Reduced manufacturing cost by elimination of vacuum and the option to fabricate the entire lower tile assembly in one piece.]

Commercialization Plan

Improved UV performance – Incom will incorporate bi-alkali photocathodes and top window materials, such as fused silica glass, using novel strategies to address the CTE mismatch between window material and the ceramic side walls to fabricate Gen II LAPPD™ with improved transmission in the near UV range.

Incom Market Forecast

Incom offers prospective customers three closely related products that come together in the manufacture of LAPPD™. These include uncoated Glass Capillary Arrays (GCA's), fully functionalized microchannel plates (MCP's), and complete 20-cm-square LAPPD™ photodetectors. The MCP is essentially a GCA with nichrome (Ni-Cr) electrode and resistive and emissive ALD coatings applied. Incom conservatively estimates a combined market opportunity, for sales of all three of these products, of $15 million over a five-year period, growing to $25 million over a 10-year period. These estimates are based upon current sales of prototype GCAs, and MCPs to prospective customers, as well as expressed interest from potential early adopters, for LAPPD™.

LAPPD Photodetector Tiles - Early Adopters:

The market for LAPPD™ appears to be very robust. In November 2013, Incom hosted a first "Early Adopters Users" meeting, which clearly demonstrated that there is very strong interest in Incom supplied LAPPD™ Photodetectors. This meeting attracted over 24 technical leaders and Principal Investigators, representing 17 High Energy and Nuclear Physics programs, who expressed interest in being 'early adopters' of LAPPD™ technology. Each of these "early adopters" provided a synopsis of their program objectives, status of funding, device specifications, schedule and number of required detector tiles and program success criteria. Since 2013, Incom has maintained contact with these "early adopters" to understand their needs and update their requirements. New applications have also been identified such as plenoptic imaging; LAPPD™ is the only detector capable of capturing light at the single-mode limit (diffraction-limited optics and time-bandwidth product of 1), which opens entirely novel capabilities in photonics. One "early adopter" application that is particularly relevant to the Gen II design, and to this grant application, is the eIC program. The synopsis for that program, recently updated by Dr. Mickey Chiu, Staff Scientist at BNL follows:

ePHENIX or MEIC experiments at BNL or JLAB - eIC Fast TOF, DIRC, or RICH

1) PI's and Sponsors: Mickey Chiu, Staff Scientist, BNL, Carl Zorn, Pawel Nadel-Turonski, JLAB, sponsored by the Department of Energy Nuclear Physics Office.
2) Objective / Mission: install the LAPPD™ MCP-PMTs into a large detector(s) at a future electron-Ion collider facility (eIC). The eIC is a large collider facility which is being proposed for funding by the Department of Energy Nuclear Physics Office, and is to be built at either BNL or Jefferson Lab. This eIC facility will explore QCD and the fundamental nature of nuclear matter. The detectors at the eIC will require strong capability in particle identification, and currently designs for a TOF, DIRC, and RICH are being studied and optimized. To use the TOF technique, we require timing detectors which can achieve 10 picosecond time resolution, while for the DIRC and RICH their performance will improve with increased photoelectron yield.

   The eIC isn't expected to start data taking until 2027! First detectors for eIC will be deployed around 2022 as shown in **Error! Reference source not found.**. Prior to that, as early as 2016, LAPPD™ will be required for test and evaluation, including testing performance when

Commercialization Plan

exposed to a magnetic field. Tentative plans are being made to conduct this type testing in collaboration with Carl Zorn at Jefferson Labs. Detector cost will be an important consideration in any decision to use LAPPD™ MCP-PMTs (DOE NP usually tries to keep a subsystem cost at the ~$10M level, with a total experiment cost at $100M). Estimates of LAPPD™ use assume instrumentation of the DIRC and RICH from the MEIC detector, and the psTOF in the ePHENIX hadron endcap. Use of MCP-PMT for the barrel in ePHENIX, (approximately 10 m^2 of coverage, or 243 LAPPD™s) is less liked since the B-field is transverse to the MCP-PMT. TOF in the MEIC detector is expected to only require about 100 ps, opening potential for low cost options such as current glass Multigap Resistive Plate Chamber (mRPC) technology.

Table 1 – eIC Detector Requirements (8"X8")

Program	2016	2017	2022	2023	2024	2025	2026	Total #
LAPP™ Performance Testing	1	1						
DIRC (MEIC Detector)				25	25	25	25	**100**
psTOF (ePHENIX Hadron Endcap)			100	100	100	100	100	**500**
RICH (MEIC Detector)						25	25	**50**
Total =	**1**	**1**	**100**	**125**	**125**	**150**	**150**	**652**

The Gen II LAPPD™ incorporates needs expressed by these early adopters. [Table 2 summarizes principal investigators, program titles, timing, initial tile needs, and total tile needs for each of these early adopter demonstration programs. The projected near-term total of approximately 300 tiles does not include estimates (marked with *) provided for some programs where the planning is still in the very early stages, or for programs where the tile design differs from the LAPPD™ standard or GEN II format.

[Analysis of Competition

[Table 2 – Early Adopter Programs wishing to use LAPPD style photodetectors]

PRINCIPAL INVESTIGATOR & SPONSOR	PROGRAM TITLE	Program Timing	INITIAL # TILES	TOTAL # TILES
Shawn Usman (NGA), John Learned (U. of Hawaii)	mini-TimeCube (mTC) collaboration*	Q-3 2016	4	104
Bill Worstell, Incom Inc., Henry Frisch, Enrico Fermi Institute	Large Area Detectors for PET Scanning	ASAP	2	6
Henry Frisch (U of Chicago)	LaRiaT (Liquid Argon Beam-line Experiment at Fermi Lab)	ASAP	5	5
	Sub-psec TOF for collider vertex and particle ID	ASAP	6	6
	Track reconstruction in a small water Cherenkov counter			
	Double-beta decay development			
	Calorimeter development			
Mayly Sanchez and Matthew Wetstein, Iowa State University (and collaborators)	Atmospheric Neutrino Neutron Interaction Experiment	Q-2 2014	2	20

Commercialization Plan

Andrey Elagin (U of Chicago)	Neutrino-less Double-Beta Decay	Q2 - 2016	1	72
Artur Apresyan, Spiropulu , Newman, Bornheim (CalTech)	Precision timing detector for the CMS experiment at the Large Hadron Collider	2023	2	*10m2
Vivek Nagarkar - Radiation Monitoring Devices	“Fast-Timing Large-Area Detector for Neutron Scattering”	2016	1	1
Anatoly Ronzhin & Pasha Murat (Fermi Lab)	Crystal calorimetry for the Mu2e experiment	2018	TBD	*2000
Mickey Chiu, BNL, Carl Zorn, Pawel Nadel-Turonski, JLAB	ePHENIX or MEIC experiments at BNL or JLAB - eIC Fast TOF, DIRC, or RICH	2016 - 2017	2	*652
Nikolai Smirnov Dick Majka, J. W. Harris (Yale)	Barrel time of-flight for a future Electron-Ion collider	2018	TBD	*1,250
	Forward particle detection in ALICE at the LHC.	2018	TBD	*50
Erik Brubaker, Sandia National Lab/CA	Single-Volume Neutron Scatter Camera	Q2-2015	2	6
John Learned, University of Hawaii, and Virginia Tech	Search for Neutrino-less Double-Beta Decay (NuDot) Using Fast Timing Detectors		1	72
Bernhard Adams, Incom , Matt Wetstein, Iowa State University and Marcel Demarteau, ANL,	Plenoptic Acquisition Imaging Knowledge Experiment	2017	1	?
	TOTAL =		**29**	**292**

Commercialization Plan

[Table 3 compares various photodetector specifications, compared to anticipated eIC needs, and rates different detector technologies that might be considered for the eIC application, including the following :

- LAPPD™ = Large Area Picosecond Photodetectors
- Gen II LAPPD™ = Next Generation LAPPD™ for improved performance and lower cost
- Planacon = Photonis Photomultiplier Tube, with area of 50.8mmX50.8mm and cost of $11,000 each.
- SiPM = Silicon Photo Multiplier – Not viewed as a contender
- GEM = Gas Electron Multiplier – in development much longer compared to LAPPD. Most of the work is being done in Europe. GEM foils. Difficult for large areas.
- Ma PMT = Multi Anode Photo Multiplier Tube

SiPMs are singled out because they are commercially available now, and are sometimes suggested as an alternative to MCP-based photodetectors. The "assessments" of SiPM, GEM and MaPMT, highlighted in grey, was provided by Carl Zorn, who is a Detector Systems Physicist at the Thomas Jefferson National Accelerator Facility. He is evaluating MCP-PMT such as LAPPD™ for use in the eIC program, which is a "target" application for our Gen II LAPPD™ Proposal, but the evaluations apply to other applications equally well. Characterization of LAPPD™, Gen II LAPPD™, and Planacon technology, and the targets presented for eIC were drawn from a number of sources, including helpful conversations with Carl Zorn, with Mickey Chiu (at Brookhaven National Laboratory), as well as Bob Wagner and Marcel Demarteau from ANL. The table addresses a number of device requirements and characteristics. Here are a few key points:

1. **<u>The "Big One" is Detector Cost!</u>** Assuming a high volume application, with thousands of detectors, Incom projects being able to manufacture and market Gen II LAPPD™ at a cost of $10,000 each. In that scenario, SiPM are 4X more expensive (detectors only, no electronics) compared to the Gen II LAPPD™. Planacons will be 17X more expensive compared to Gen II LAPPD™.
2. **<u>System Costs</u>** - System costs include electronics, special housings, connectors, and other variables in addition to the detector itself. It is premature to have reliable estimates on "system costs" except to anticipate the following: The Gen II LAPPD™ will have a very robust package, which, with the pixelated "inside-out" anodes, will simplify electronic connectivity to the device. When large numbers of detectors are considered, complex connectivity, including the number of connectors, emerge as a significant cost and reliability issue.
3. **<u>Background Noise</u>** - Historically has been a problem with SiPM, to the extent that low temperature operation has been required for some of these detectors....we understand that some of the latest SiPM might have somewhat mitigated this problem, but we are confident that still does not compare favorably with LAPPD™. LAPPD™ have extremely low background noise / dark current, which will be improving even further with Gen II designs.
4. **<u>Radiation Hardness</u>** - remains a problem for SiPM. They are quite sensitive to Neutron damage which makes them so noisy as to make them useless for our target applications. On [Table 3 SiPM was rated as 'Poor', for this characteristic. The LAPPD™ is intrinsically radiation hard, and it will be evaluated as part of Phase II of our GEN II LAPPD™ effort.

The Gen II LAPPD™ represents an important strategy for cost reduction, and high volume manufacturing.]

B) Intellectual Property

Commercialization Plan

Incom’s IP strategy addresses three technologies that together comprise the LAPPD:

Glass Capillary Arrays - Incom has developed a novel “Hollow Core” strategy to build capillary arrays, eliminating costly chemical etching of sacrificial core glass characteristic of prior art techniques. Incom’s ability to fabricate microchannel arrays builds upon over 40 years of progressive manufacturing and development experience in the fused fiber optic field. These glass processing technologies and the methods used to fabricate Incom Glass Capillary Arrays are protected by internal procedures intended to safeguard certain Incom technology as “trade secrets”.

Microchannel Plates – Glass Capillary Arrays are transformed into large area, low cost microchannel plates (MCP’s) by application of resistive and emissive layers, applied by Atomic Layer Deposition (ALD). Incom Inc. has licensed ALD coating technology from Arradiance, Inc. Sudbury, MA, and from Argonne National Laboratory.

In 2013 Incom Inc. licensed ALD MCP coating technology from Arradiance, Inc. Arradiance uses different coating chemistries than the Argonne technology, providing Incom with multiple options to select from depending on specific application requirements. Incom has licensed a portfolio of nine issued patents (U.S. No. 7,408,142 B2; U.S. No. 7,759,138 B2; U.S. No. 7,855,493; U.S. No. 8,052,884 B2; US. No. 7,977,617; U.S. No. 8,134,108; U.S. No. 8,227,965; US No. 9,064,676; and U.S. No. 8237,129 A) and seven pending patents from Arradiance.

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Vivek Nagarkar - Radiation Monitoring Devices	“Fast-Timing Large-Area Detector for Neutron Scattering”	2016	1	1

Commercialization Plan

Anatoly Ronzhin & Pasha Murat (Fermi Lab)	Crystal calorimetry for the Mu2e experiment	2018	TBD	*2000
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Commercialization Plan

[Table 3 – Comparison of Photodetector Performance]

Specification:	eIC Targets	MCP-PMT			SiPM	GEM	Ma PMT
		LAPPD	Gen II LAPPD	Planacon			
Magnetic Field Sensitivity	Can't be calibrated out. Important to all experiments	Fair? (TBD)	(TBD) design optimized for Mag Field use Reduced gap, increased voltage	Fair? (TBD)	very good	good	poor
Radiation Hardness	Concern for photocathode,	Good? (TBD) - Package & MCPs contain Boron	**Excellent (TBD)** - High purity Boron free package and MCP	Good? Lead containing MCPs	**Poor – lattice damage & dark current**	good	good
Average Rate Capability (Drop of Gain at high rate)	eIC rates not dramatically high in barrel and endcap (high Khz/cm^2)	Good - 100's Khz/cm^2	Good - 100's Khz/cm^2	Good	good	good	good
Single Photon Detection (Quantum efficiency of the Photocathode X Collection Efficiency)	Cerenkov Light for psTOF, RICH, and DIRC	Good with Borosilicate Window	Excellent - Enhanced with UV transmitting window	Excellent with UV window	good	poor	fair
Dark Rate	High priority, but tubes generally very good for dark rate.	Very good with Borosilicate MCP	**Excellent with C-14 MCP -** <0.1 cnts/(sec cm^2).	Fair?	**Poor - high dark noise**	Fair	low
Photodetector Time Resolution Transit time spread & time resolution (bandwidth) of read-out electronics	Dominated by MCP	Excellent: 50 psec for single photons, 5 psec for large pulses	**Excellent: 50 psec for single photons, <5 psec for large pulses**. Further improved with 10-micron MCP	Excellent	**good**	Poor	fair
Position, Single Photon Spatial Resolution	Key is pixelated anode. Position resolution should be sufficient with 3-4 mm pads	For large pulses - 5 mm pitch delay line strips, 0.5 mm for single photons	3mm pixel with 0.5mm resolution (or better, can be further improved with more pixels, enhanced design, etc.)	<	mm	100-micron	mm
Instantaneous Rate Capability	Spatial resolution would be important to separate multiple Cherenkov rings from each other.	10 photo electrons	100s photo electrons over 1 LAPPD (can be further improved with more pixels)				
UV Performance	UV Performance Highly desirable?? YES, very important, for Cerenkov sensitivity	Poor (non-transmitting Borosilicate window)	Excellent (Fused Silica Window)	Excellent (FS Window)			
Compact & Thermal Design suitable for integration into system	Highly desirable?	Better – Thin profile, and able to be tiled	BEST – compact, can be tiled, and low power (less heat)	Good	Good (more heat)	??	Poor (Fat)
Mechanically Robust		Good	Better (stronger, tougher, ceramic lower tile assembly with FS window, no pins)	Robust due to small size	Excellent	Delicate	Delicate
Operating Temperature Tolerance	TBD Hall is kept temp controlled, temp excursions, modest 20-30C						
Projected High Volume Unit Cost & Cost/m^2	17X reduction in cost compared to Planacon	$30K ($.75M/m^2) .75X	$10K ($.25M/m^2) **.25X**	4.25M/ m^2 4.25X	**$1M/m^2 1X**	low	$1M/m^2 1X
Projected System Cost with Electronics	Wave form sampling electronics Cost of connectors can be significant	Cheaper due to far fewer (28) Channels, PSEC Chip ($50)	**Connector Free Design:** Printed circuit board capacitive coupling to bottom of detector	Many more pixels to connect			

Commercialization Plan

Incom has also licensed US patent (8,969,823 B2) titled Microchannel Plate Detectors and Methods for their Fabrication from ANL, which Issued March 3, 2015. Incom has also optioned additional patents from ANL titled Tunable Resistance Coatings (US 8,921,799 B2) and ALD Reactor for Coating Porous Substrates (Showerhead Design). In addition to a patent licensing agreement, Incom has entered into an extensive multi-year technology development and transfer program with Argonne National Laboratory.

Large Area Picosecond Photo Detector (LAPPD™) –

Many of the design features of the LAPPD™ have been patented by the University of Chicago. Furthermore, implementation of LAPPD™ depends on use of licensed technology from ANL for fabricating MCPs.

Incom Inc., ANL and the Technology Transfer department at the University of Chicago have on-going discussions with the goal of developing a unified strategy for LAPPD™ patent and trademark licensing. Discussions include Argonne and UC combining patent rights on the joint invention of the detector design, UC taking the lead for licensing, and royalty and license fees, etc. coming due when commercial activity is imminent.

The Term LAPPD™ has been trademarked by U of Chicago:

- LAPPD™ is defined as a microchannel plate (MCP) based photodetector, capable of imaging, and having both high spatial and temporal resolution in an UHV hermetic package with an active area of 400 square centimeters.
- The trademark is for: a photodetector; Scientific apparatus and instruments for measuring the time of arrival and position of photons; Scientific apparatus and instruments for measuring the time of arrival and position of relativistic particles. The "mark" consists of standard characters without claim to any particular font, style, size or color.

Incom Inc. has an option to license the "trademark", as well as two issued patents (8,604,440 and 7,485,872) as well as four pending patent applications. UC has also filed a provisional patent application covering the use of the LAPPD™ for PET imaging and some specific novel approaches to PET system design that are enabled by the LAPPD™.

Incom Patent & Trade Secret Strategy

Incom aggressively protects its capital-intensive glass technology by implementing strategies to insure that it is kept 'trade secret'. Incom, Inc. also seeks to obtain trademark rights for unique products that it develops as a form of branding key products. More general safeguards have also been taken that help to protect corporate IP. Since so much of the "know how" of Incom's products reside with the employees, the management of Incom, Inc. works hard to maintain a personal relationship with employees, and also instructs them on the importance of maintaining the confidentiality of Incom technology. All employees must sign a nondisclosure agreement at the time of employment. Also, computer passwords have been implemented to avoid unauthorized access to computer files, and access to the building is restricted.

Patent Counsel - The patent legal counsel used by Incom is: Bainwood, Huang & Associates, LLC, Highpoint Center, 2 Connector Road, Westborough, MA 01581. Contact is typically made every 3 to 5 months with the Incom, Inc patent legal counsel to review the status of applications and address any outstanding IP questions.

C) Company/Team

Commercialization Plan

1. Incom Inc. Company Origins – Incom Inc. is a privately held C Corporation. As the world leader in the field of fused fiber optics, Incom, Inc. is forging new paths in the development and manufacturing of components used in high-quality image transfer devices. Founded in Southbridge, MA, "The birthplace of fiber optics", Incom has been developing innovative and unique fiber optic technologies for over 42 years. Incom, Inc., was founded in 1971, as a direct descendent of American Optical Laboratories.

2. Incom's R&D Technical Team

Michael R. Foley - Incom Development Engineer (Since 2010), and Principal Investigator (PI), Mr. Foley is responsible for the finishing of glass capillary arrays and with the processing of the detector tile kit components. Mr. Foley received a B.S. degree from the Michigan Technological University and a M.S. from The Pennsylvania State University.

Mark A. Popecki - Incom Research Scientist (since 2014) - Dr. Popecki is responsible for establishing and supporting MCP and LAPPD^{TM} measurement and testing at Incom Inc. Dr. Popecki earned a Ph.D. in Physics: University of New Hampshire, Durham, NH, 1991.

William A. Worstell – Incom Senior Research Scientist (Since 2015) Dr. Worstell is **a** physicist and imaging engineer with broad and deep experience in high-energy and nuclear physics instrumentation, and in medical imaging device detector physics and instrumentation, product design and development. He also has extensive experience in device calibration and background data corrections and image reconstruction, especially for computed tomography. Dr. Worstell completed a Ph.D in Experimental High Energy Physics, at Harvard University, and Bachelor of Arts cum Laude in Applied Mathematics (Physics) at Harvard College.

Christopher A. Craven - Incom Senior Development Engineer (Since 2007) Mr. Craven has 31 years of experience in the development of a wide range of methods and equipment for the fabrication of advanced materials. Mr. Craven received an SB in Materials Science Engineering from MIT.

Alexey Lyashenko - Incom Photodetector Research Scientist (Since 2015), responsible, for "integration & sealing" of detector tiles. . Dr. Lyashenko holds a Ph.D in Physics from the Weizmann Institute of Science, Rehovot, Israel, and an MSc and BSc in Physics from the Novosibirsk State University, Novosibirsk, Russia.

Bernhard W. Adams- Incom Senior Research Scientist (Since 2015) Dr. Adams holds joint appointments as visiting scholar, University of Chicago, and Adjunct physics professor, Illinois Institute of Technology. Dr. Adams has been involved in the LAPPD^{TM} project from the outset, mostly in the characterization of temporal and spatial resolution. Has also worked on the theory of optical coherence and proposed a way to optimally match the coherence properties of synchrotron radiation to the specific experimental needs [41]. He is the inventor of LAPPD^{TM} applications in ghost imaging, thermal lidar, and 'seeing through fog". He completed his PhD in experimental physics (Dr. rer. nat.), at the University of Munich, Germany, July 1995.

Aileen O'Mahony - Incom ALD Research Scientist (since 2012), Dr. O'Mahony has led efforts for transfer of licensed Atomic Layer Deposition (ALD) processed from Argonne National Laboratory to Incom. Dr. O'Mahony holds a Ph.D. in Chemistry from University College Cork where her thesis addressed the ALD of high-k oxides for application as the gate oxide layer in III-V CMOS devices.

Commercialization Plan

Till Cremer - Incom Atomic Layer Deposition (ALD) Research Scientist, (Since 2015) Dr. Cremer is responsible for the operation of the ALD system used for coating microchannel plates (MCPs). Dr. Cremer holds a Ph.D in Physical Chemistry from Friedrich-Alexander University, Germany.

Justin L. Bond – Incom Research and Development Technician (since 2013). Mr. Bond is involved in designing and fabricating development fixtures, process development and process execution used in the manufacturing of microchannel plates and related tasks. Mr. Bond has a HSD from the school of Shepherd Hill in Dudley, Massachusetts.

Michael E. Stochaj - Incom Senior Research and Development Technician (since 2013). Mr. Stochaj has 26 years of semiconductor process development experience and has spent the last 4 years on the Process development and execution of micro channel plates and detector lower tile assemblies (LTA) for the LAPPD project. Mr. Stochaj has an AS in computer science from Newbury JR College.

Melvin Aviles – Incom R&D Technician (Since 2012) Melvin Aviles is responsible in supporting the development and optimization of Glass Capillary Array (GCA) grinding, forming, polishing and cleaning procedures. Mr. Aviles also supports the development of the LAPPD™ Lower Tile Assembly (LTA) procedure. Melvin Aviles earned a B.S. degree in Chemistry from the University of Puerto Rico at Cayey, Puerto Rico.

2. Incom's Executive Management Team

Anthony M. Detarando (Chairman of the Board, employee since 10/1/1971) -Executive with 42 years of experience in the field of fused fiber optics. Anthony studied Mechanical and Industrial Engineering at Cornell University and now serves as Retired President and Chairman. His background and expertise includes all phases of the fused fiberoptic industry and its technology including product design, manufacturing, sales and marketing. He has been involved with Incom, Inc since its inception in 1971.

Michael A. Detarando (President and CEO, employee since 5/26/1992) Executive with 21 years of experience in the field of fused fiber optics. Michael studied Mechanical Engineering at the University of Miami. He is presently serving as President and CEO. His background and expertise includes all phases of the fused fiber optic process and its technology, including product development, sales & marketing, manufacturing, and engineering.

Joseph A. Krans (Director of Operations, employee since 9/20/1999) - Engineer with 29 years of experience in the field of fiber optics. Joe studied Physics at Worcester Polytechnic Institute and is presently serving as Director of Operations at Incom Inc. His background & expertise includes glass materials, fiber drawing & pressing, optical finishing, fiber optics, acid etching and clean room technology.

Michael J. Minot (Director Research & Development, employee since 4/1/2006). – Dr. Minot is a Research and Development Executive and Scientist with expertise in Glass Science, Fiber Optics, Photonics, and Advanced Materials. He has extensive technical and general management as well as consulting experience, including over 40 years of progressively higher management experience spanning Fortune 500 and venture-financed startup Companies. He presently serves as Principal Investigator for the DOE funded "Technology Transfer Opportunity" program establishing pilot production and commercialization of LAPPD™. He has represented Incom in the LAPPD Collaboration, and has also been an independent consultant to that program. Earlier in his career, Dr. Minot spent 15 years with Corning Glass Works in a variety of senior positions in manufacturing, engineering and R&D including the scale-up of fiber optics manufacturing. Dr. Minot Dr. Minot received his BA in

Commercialization Plan

Chemistry from New York University, his MS, PhD in Chemistry from The Johns Hopkins University, and completed Postdoctoral Studies in Material Science at the University of Maryland.

David Welker - Director of Polymer Products at Incom and general manager of Paradigm Optics, which was acquired by Incom Inc. in November, 2011. Dr. Welker co-founded Paradigm Optics in May 2000 while a graduate student in the Physics Department at Washington State University. Since its inception, Paradigm Optics has produced optical fiber, capillary tubing, capillary arrays, and fiber optic faceplates exclusively from polymer materials. Dr. Welker has assembled an intellectually diversified, highly motivated, technical and manufacturing team with background and experience in Analytical Chemistry, Nuclear Engineering, Physics, and Engineering Physics at the polymer division to help conduct this research. Dr. Welker received his BS degree in Physics from California State University, Hayward and his PhD in Polymer Science from Washington State University.

Steven Morrill, CPA (Director of Finance, employee since August 2009) – with 24 years of experience in Finance and Planning. Mr. Morrill studied Finance at Assumption College in Worcester, MA. His background includes "Big Four" Public Accounting, Fortune 500 manufacturing, and privately held companies. His areas of expertise include Forecasting, Strategic Planning & Analysis, Accounting, and Organizational Psychology.

Maura L. Grossman, (Director of Human Resources, employee since November, 2010). With 17 years of experience in Human Resources, Maura studied Education at the National University of Ireland and Business Administration at University of Massachusetts, Amherst. She presently is serving as the Director of Human Resources at Incom, Inc., Maura's background and expertise is in the areas of Recruiting & Employment, Compensation and Benefits, Employee/Employer Relations, Health & Safety, Organizational and Employee Development, Business Leadership and Strategic Planning.

Michael E. LeBlanc, (Director of Finishing Operations and Compliance, employee since April, 2006) - With 33 years of experience in Quality and Compliance, Michael attended Johnson & Wales University where obtained his BSMET and is an accredited Export Compliance Professional. He served in the United States Navy for 10 years in the Nuclear Power field. His background includes building construction and maintenance, machinery erection and repair, project management, hazardous materials and hazardous waste management, ISO 9001/2008, and manufacturing. Michael has worked for Fortune 500 companies as well as privately held entities.

Gary G. Tavares, Director of Quality, employee since October 2010 – with 30 years of experience in Engineering, R&D, and Product Development. MSME from the University of Connecticut, certified New Product Development Professional. His background includes experience in turbo machinery engineering and managing consumer product development programs for Fortune 500 companies. Areas of expertise include Engineering, Strategic Planning, and Change Management.

3. Additional Corporate Resources

In addition to staff, Incom Inc. draws upon the following resources which support the Companies commercialization needs:

a) Patent Counsel - The patent legal counsel used by Incom is: Bainwood, Huang & Associates, LLC, Highpoint Center, 2 Connector Road, Westborough, MA 01581
b) Corporate Counsel –Morgan, Brown & Joy, Boston, Massachusetts
c) Financial, Accounting – O'Connor, Maloney & Company PC, Certified Public Accountants Worcester, MA 01608
d) Board of Directors (Members & Regularity of Meetings) – This Board meets monthly:

Commercialization Plan

- Anthony M. Detarando – Chairman of the Board
- Michael A. Detarando – President & CEO
- Anthony J. Detarando
- William Hanley
- Leonard DiGregorrio

END.