Applied Laser Tooling

edited by

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Preface

The invention of the Laser, 25 years ago, has become an innovation with established industrial technology extended through diverse areas of economic viability (a 25% sales annual growth), and promising market perspectives.

In organizing an European Intensive Course on Applied Laser Tooling, it seemed opportune to bring together an international group of scientists to provide an appraisal of industrial Lasers, system integration, and sensitive areas of Laser beam material interaction, while emphasizing those areas which promise to have major impact both in science and technology.

Tutorial papers and reports on latest developments both in research and industrial manufacturing were complemented by video and film projections to show the wide variety of applications in industry, stressing the combination of Lasers with other technologies, mainly CNC and Robots.

The large participation by the industry fulfilled the intended interaction and cross-fertilization between the scientific, technological and industrial community, reinforcing the innovative capacity readily demonstrated at panel discussions.

It was neither possible nor planned to cover all the aspects in full depth. Efforts were addressed to selected areas where discussion of advanced knowledge and technology topics would stimulate further progress of Laser tooling (in main directions: software, hardware and peopleware).

Laser tooling was then discussed in light of its major applications covering Laser beam robotic manipulation towards flexible manufacturing systems.

The following articles give a fair account of the course programme.

Some of the texts were written from lecture notes. While the writers asked the lecturers to review the material, the Editors will bear an unexpected enlarged responsibility.

At closure there was a sense of excitement towards future possibilities mixed with pleasant recollections of the friendly atmosphere enjoyed at Samil.

This volume attests the pleasure of sharing this experience with others interested in the field.

Olivério D.D. Soares
Mariano Perez-Amor

Samil, Vigo, 1986

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APPLIED LASER TOOLING

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Abstract

Laser technologies are credited as one of the essential components of present pattern of the industrial competitive transmutation. Companies to respond with flexibility and efficiency are led to the technological combination of Laser, Robots and Optical Fiber systems to increase competitiveness through high productivity, innovation and quality assurance. Industrial and economical relevant aspects of the Laser era are dealt with while emphasizing the Laser processing of metallic and non-metallic materials, microelectronics fabrication and processing of semiconductors.

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1. Lasers and Industrial Dynamic Competition

"By the XXI century the photon will replace the electron as the element of technological development"

Guy Denielon
ANTRT - Association Nationale de la Recherche Technique

Power Lasers have already been around for a considerable time but only recently came the expanding use of their full potential for manufacturing. Many manufacturers seem rather cautious of introducing Laser technology into their factories which may be due to yet a certain mystery around the topic. The present book hopefully will give some contribution to dispel these hesitations and bring Laser technology to the understanding of their benefits and limitations to reluctant industrialists.

The study and development of Laser applications, namely in material processing is in constant development further increasing the perspectives to the industrialist. The Laser relevance derives from its innovative capacity to produce:

i) high technology
ii) high knowledge
iii) flexible energy and information handling

with consequent adaptability to manage the change in the process of transfer of science into economically productive technology, based on the recognized essential trends:

i) high productivity through high production rate and complete quality control cycle.
ii) innovation to enforce the dynamic comparative advantages, essential ingredients to the economic recovery and growth
iii) miniaturization for flexibility, adequacy, and saving of raw material and energy.

These are the progress dynamic vector components, to overcome the present crisis, and promote a sound and stabilized development of the new economy progressively technology oriented.

These progress components proceed from the need for an economical improvement through the evolving market competition that is usually linked to productivity features (quality and rate), and innovation.

However, innovation is a matter of great controversy, particularly when looking at high technology (a hopeful portent for eventual economic recovery and growth). An aspect then discussed further on is economics of Laser applications. This has been brought into the course intentionally, to make it to emerge the difference between invention, discovery, and innovation (1), notably when technology and science are becoming a service beyond a mere product. Further, it should be emphasized that innovation far from being peripheral must be considered a powerful though complex driving force that works its way through the economy and molds it, Fig. 1. Its success is anchored on a dynamic competition rather than a consequence of static economic growth with a pure reproduction of products or services. It

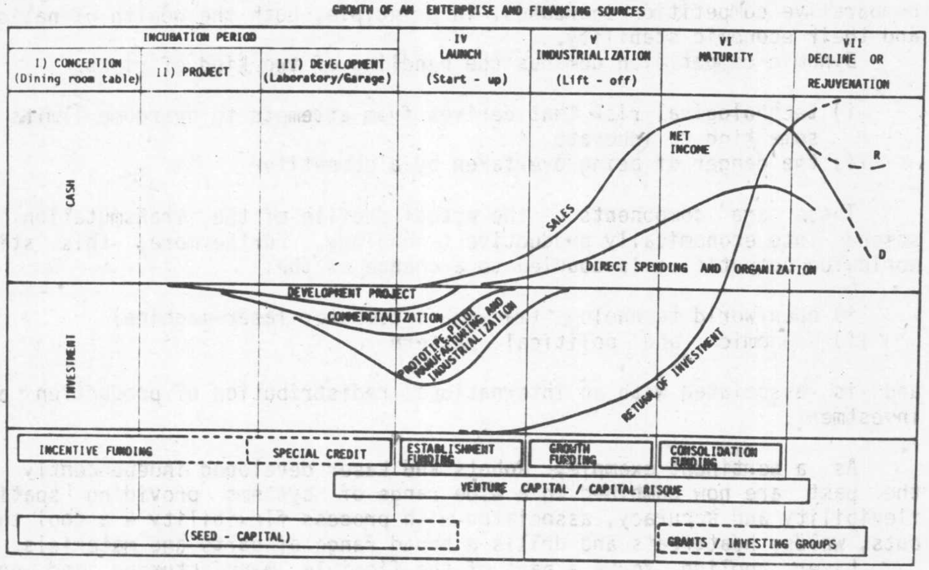

Fig. 1: Economical cycle of innovation (12)

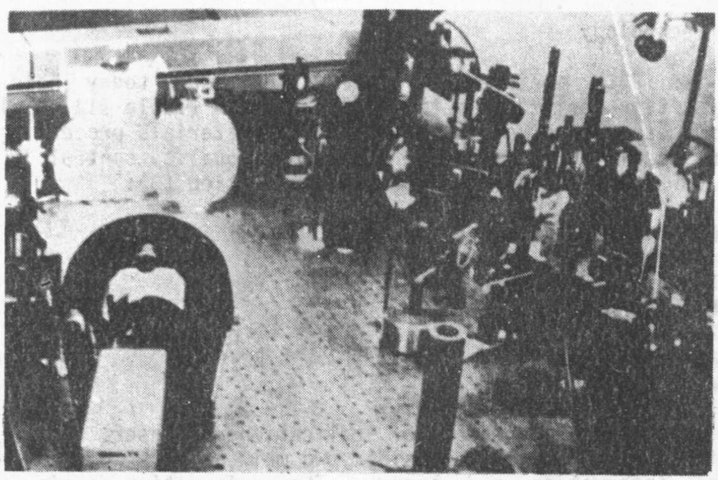

Fig. 2: Stroboscopic and Phase-modulated Moiré-holography set-up as an Optical Metrology technique for vibration studies (Applied Physics Laboratory - University of Porto)

is the competition within industries engaged in using renewed technological means that governs how rapidly new technologies are incentivated to evolve (another present case is the microprocessor market). This dynamic comparative competition increases, in principle, both the wealth of nations and their economic stability.

Dynamic competition demands the handling of two kind of risks:

i) technological risk that derives from attempts to overcome limits of some kind to innovate.
ii) the danger of being overtaken by a competitor

These are components of the actual profile of the transmutation of science into economically productive technology. Furthermore, this stiff worldwide competition is coupled to a change of the:

i) open world technology (man-robot-computer-laser-machine)
ii) economic and political pattern

and is associated with an international redistribution of production and investment.

As a pertinent example, Robots and Laser developed independently in the past are now combined in a wide range of systems providing spatial flexibility and accuracy, associated with process flexibility - a tool that cuts, welds, heattreats and drills a broad range of parts and materials.

Laser tooling forms a part of the flexible manufacturing and non-manufacturing concept.

2. Laser Technology

On its 25th anniversary (Table I) the Lasers today hold a secure market position derived from their capabilities (Table II) to play a part in all stages of manufacture, from the raw materials processing to finish operations assembling, inspection and product quality control.

The unique characteristics of Laser radiation (3):

i) Coherence (spatial, temporal)
ii) Divergence
iii) Energy (power, focusing)
iv) Mode structure
v) Polarization
vi) Pulse rate or CW
vii) Wavelength

determine the increasing number of applications of Laser.

Artificially one may consider two main aspects of interaction of radiation: information and energy. The information domain relates to processes and corresponding techniques for metrology, sensing, processing and control (4), (Table III), serving a vast domain of innumerable applications, Fig. 2. These applications result from the fact that Laser radiation can, in principle, be entirely controlled in amplitude, phase, monochromaticity, coherence, polarization, directivity, the Laser beam

TABLE I

LASER HISTORIC (6)

LASER TYPE	PUBLICATION	LABORATORY
IR	A.L. Schawlow and C.H. Townes Infrared and Optical Masers Phys Rev. 6 (1958) 112	Bell Columbia
SOLID	T.H. Maiman Stimulated Optical Radiation in Ruby Nature, August 6 (1960) (Report results from 16th May 1960)	Hughes
GAS	A. Javan, W.R. Bennet, D. Herriot Continuous Maser Oscillation in a Gas Discharge with He-Ne Mixture Phys. Rev. Lett. 6 (Feb 1961) 106 (Rec. 10th Dez. 1960)	Bell
SEMICONDUCTOR	R.N. Hall, G.E. Fenner, J.D. Kingsley, T.J. Soltys and R.O. Carlson Coherent Light Emission from Ga As Junctions Phys. Rev. Lett. 9 (1962) 366 (Rec 24th Sept 1962)	G.E.C.
DYES	P.P. Sorokin and J. Laukard Stimulated Emission in Dyes IBM Journal R&D 10 (1966), 162	IBM

TABLE II (2)

LASER USAGE SAMPLING

RESEARCH	SOLID STATE (Glass-Crystal)	Al_2O_3 Cr^{3+}; YAG Nd; Glass: Nd; YAP: Nd; YAG: Er G SGG, Cr Nd, Alexandrite
	GAS	Noble Gas: He-Ne; Ar^+; Kr^+; Xe^+ Metallic Vapour: He-Cd; He-Se; Cu; An Mollecules: CO_2; CO; HF; DF Excimer: X_eF; Kr f
	LIQUID	Dye: Rhodamine GG; B; Coumatine
	SEMICONDUCTOR	Ga As; Ga Al As; Ga As P Pb, Sn, Te
	PICOSECOND LASER	Ring lasers
	INDIRECT LASERS	Laser pumped media Gaseous, Raman Shifted NL SHG, THG, OPO
	NEW SOURCES	X-Ray Laser Free Electron Lasers
SCIENTIFIC INSTRUMENTATION	NON-LINEAR OPTICS	Harmonic Generation Optical Parametric Oscillations Raman Effect (spontaneous and stimulated) Brillouin Effect (spontaneous and stimulated) Four-wave-mixing Optical Phase Wave Conjugation
	SPECTROSCOPY	High Resolution Spectroscopy Non-linear Spectroscopy Saturation Spectroscopy
	PHOTO-INTERACTION	Thermonuclear Fusion Selective Photochemistry Isotope Separation
	BISTABILITY	Logic Circuitry Processors Computer Sensors
	SYNERGETICS	Transition Order-chaos
INDUSTRIAL TOOL	METROLOGY	Length Standards Distance Measurement Telemetry and Triangulation Anemometry Dopler Remote Monitoring Optical Radar Alignment Sensors Survey: Inspection, Quality Assurance and Control
		HOLOGRAPHY Display - transmission or reflection white light rainbow hologram Photoresist - Reflection Embossed, Head-up displays Optical Elements - scanners, deflectors, viewfinders Non-destructive Testing - Interferometric Holography - Hybrid Fringe Analysis Crystal Growth
		SPECKLE Speckle Monitoring Speckle Photography E.S.P.I.
	MATERIAL PROCESSING	Metal Working: cutting, welding, drilling, hardening, cladding, alloying, marking Non-metallic Material Processing: wood, plastic, textile, glass, leather, wood Microelectronics Semiconductors Annealing Photochemistry LCVD Selective Processing - photodissociation, photoionization
	ENVIRONMENT PROTECTION	Analysis Pollution: LIDAR Oceanology
	MEDICAL	Surgery Photochemiotherapy
	BIOTECHNOLOGY	Selective Photochemistry Picosecond Events
	TELECOMMUNICATIONS	Optical Aerial Links Optical Fibres - network, submarine cables, LAN Integrated Optics
	INFORMATICS	Data-handling Processors Memories Computer Printing and Graphics Art
	MILITARY	Range Finder Target Designator Tactical Weapons

TABLE III

LASERS - INFORMATION

INFORMATION	Acquisition	Measurement Transducers Sensors Non-destructive Testing Inspection, Quality Assurance and Control Survey
	Storage	Data-handling Memory
	Transmission	Communications - Optical Fibres, Integrated Optics Telemetry Printing and Graphics
	Processing	Image Processing Logic Circuitry Computing Art
	Presentation	Display Scanners and Deflectors Viewfinders Holography

taking the place of carrier or reference with obvious key advantages:

i) Laser beams do not interact
ii) Optical channels are well adequate for parallel processing
iii) Optical channels are capable of very-high speeds (femtoseconds!)

The Laser radiation can efficiently and reliably be integrally controlled in intensity and focusing. This controllability, accuracy and reliability of Laser sources are the core of Laser applications in material processing, and is considered under this title of Laser Tooling, Fig.3.

Each application requires its own parameters adjustment in regard to power and energy levels, per wavelength, beam profile and modulation method. The most important being the balance between power and good beam quality, resulting in small focused spot size and highest energy density. Then, optimized use can be done of the advantages of Laser Tooling:

i) beam parameters control with consequent tight control of manufacturing process
ii) negligible forces on the pieces
iii) easy of adaptation to automation
iv) sharing of movement between Laser delivering head and piece to the optimization of production

Traditional methods of material processing are dependent on delivery of various forms of mechanical, electrical or chemical energy into contact with the workpiece. The availability of direct energy sources (5): Lasers, electron beam, and ultrasonic devices, capable of power densities in excess of 10^6 W cm^{-2} , introduced the non-contact tooling concept. Knives, drills, abrasive wheels, flames, chemicals and electrodes seen in certain industrial operations, can be eliminated, while reducing maintenance, replacement and direct labor costs.

The behavior of materials subjected to intense concentration of essential thermal energy up to 10^5 W cm^{-2} remains of central interest, in particular, those correlated with machining, welding, and surface engineering (leaving e.g. refractive index changes, electrical conductivity changes, etc).

Laser performances continue then to be explored, to established a full but still developing generation of purpose-built family of Lasers for industry, Table IV.

In parallel, concentrated efforts have been focused on system development of better automated techniques and cost-effective solutions competing with existing methods in industry.

As a result Laser technology is also growing as a horizontal technology i.e. contributing to research, development and production, percolating into almost every domain. There is then no wonder that Laser sales present an annual 35% sales growth rate.

3. Laser Tooling

Laser tooling has been used to define the answers of Laser Technologies to the production systems.

Market acceptance of industrial Lasers for production floor machining

TABLE IV

TYPICAL LASER CHARACTERISTICS

TYPE	WAVELENGTH [μm]	MODE OP.	MAX REPT. RATE [Hz]	PULSE WIDTH [ms]	MAX FOCUSED ENERGY [J cm⁻²]	MAX FOCUSED POWER [W cm⁻²]	MODE STRUCTURE	POWER TEM00 [W]	AVERAGE POWER [W]	PULSE ENERGY [J]	TYPICAL USES
He Ne	0.6328	CW					TEM00	$5\text{-}50\times10^{-3}$			Metrology
Ar	0.4519 to 0.5145	CW					TEM00	2-40			Holography Raman Spectroscopy
Ar	0.4880 or 0.5145	CW					TEM00	0.5 10			Semicondutor Annealing
CO_2	10.6	CW					MM	500	Up to 10^5		Mat. Processing
CO_2	10.6	CW				10^7	TEM00		10^3		-
CO_2	10.6	CW					MM		2×10^4		-
CO_2	10.6	PULSED (DP)	$\leq 2.5\times10^3$	≥ 0.1	10^4	10^8			300	≤ 1	-
CO_2	10.6	PULSED (QS)	$\leq 3\times10^5$	$10^{-5}\text{-}3\times10^{-4}$	10^3	10^{10}	TEM00		100	≤ 1	-
CO_2 TEA	10.6	PULSED	400	0.4					10^5		-
He Cd	0.325	CW									Photo litography
KRYPTON	0.3597 to 0.7993	CW						6			Holography Raman Spectroscopy
NITROGEN	0.3371	PULSED	to 500	10^{-3}			MM		2.5×10^5	2.5×10^{-3}	Photochemistry
Nd-Glass	1.06	PULSED	1	0.5-10			MM		10^6	0.125	Mat. Processing
Nd-YAG	1.064	CW				2×10^7	TEM00	20			-
Nd-YAG	1.064	CW				4×10^6	MM	400			-
Nd-YAG	1.064	PULSED FLASH LAMP	≤ 400	0.1-10	5×10^5	10^9	MM		400	≤ 50	-
Nd-YAG	1.064	PULSED (QS)		$2\times10^{-2}\text{-}0.3$	10^5	3×10^{11}	MM		150	≤ 10	-
Nd-YAG	1.064	PULSED (QS)	5×10^4	0.2			MM		50	5×10^{-3}	-
Nd-YAG	1.064	PULSED (DP)	≤ 400	0.1-10	5×10^6	2×10^{10}	TEM00		20	≤ 5	-
RUBY	0.6943	PULSED								1-500	Welding Drilling
RUBY	0.6943	PULSED (QS)							$1\text{-}10^{10}$		Pulsed Holography Raman - Brillouin, Vaporization

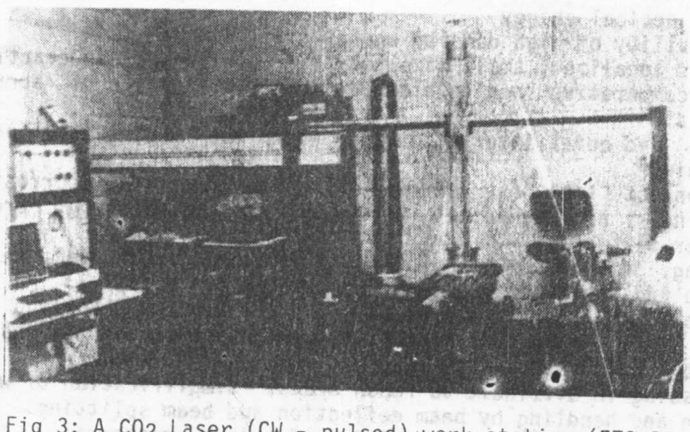

Fig 3: A CO_2 Laser (CW - pulsed) work station (E.T.S. Industriales, Univ. Santiago, Vigo)

has shown a 35% growth (2) (30,000 units by the year 2,000) with materials processing the fastest growing segment.

Machine-tools suffer from wearing, slow rate of production and the need for a large stock of tools. Lasers can emit an intensive, highly collimated beam that can be adjusted to perform most of the operations on material processing:

i) Welding (melting)
ii) Material Removal (drilling, trimming, evaporation, sputtering)
iii) Material Shaping (cutting, scribing, controlled fracturing, marking)
iv) Thermally Induce Change (localized heattreating annealing, and surface oxidation, grain size control, diffusion, zone melting, cladding, alloying)
v) Chemical Induce Change (photochemical reactions)

to name the most important.

Lasers are highly adaptable to automation and micro-machining control. Laser (high speed, precision, cleanness) and robot technologies (high accuracy, speed, and large spatial envelope) have now been combined in a major step in the advancement of flexible manufacturing system. The Laser/robot system has the spatial flexibility and accuracy of a robot and the process flexibility of a Laser. A single Laser/Robot system can cut, weld, heattreat and drill a broad range of parts and materials.

Laser tooling then is progressively taking a prominent position as a manufacturing tool for its: high-precision, life-time and specific characteristics (8):

- clean, optical energy
- availability of high density energy (10^6 W/cm^2)
- focused localized, small size (several wavelengths) interaction area with comparative negligible heating and distortion of surrounding material
- stable and quiet interaction with workpiece leading to minor after machining
- non-contact tool (no contamination, no wear, no corrosion, or breaking, no mechanical forces, exact positioning, precision, simpler fixturing)
- Tooling, fixtures, setup, and inspection, in general, relatively simple and easily adaptable to production procedures
- multiple operation in one programme cycle without retooling
- exact and flexible controllability of the processing, dimensions and quality; high reproductibility
- processing in difficult to reach areas, simplification of workpiece design and handling by beam deflection and beam splitting
- numerical control permits design of unique geometries, to shape materials that mechanical operations cannot
- processing in any atmosphere, including vacuum
- ideal possibilities of robotization and automation
- maximum degree of exploitation derived from high reliability of Laser system and the availability of on-line process control
- Laser data to achieve a desired processing in a given material can be predetermined
- process complex shapes at high speed (combined with computer controlled positioning systems)
- burn-free edge shapes (while simultaneously sealing edges for