RONALD W. WAYNANT

LASER EMISSION IN THE VACUUM ULTRAVIOLET FROM MOLECULAR HYDROGEN

Ronald W. Waynant, John D. Shipman Jr. Raymond C. Elton and A. W. Ali

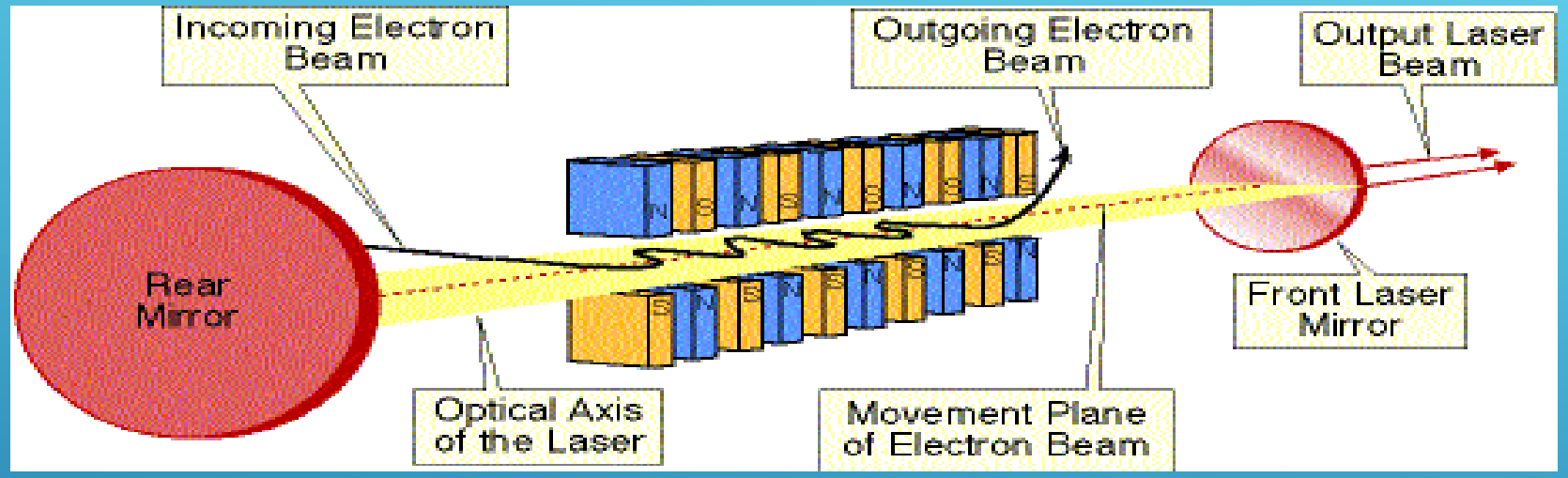
Abstract—A unique gas laser system suitable for achieving more than a 100-kW peak power in the vacuum ultraviolet spectral region near 1600 Å is described. First, the theory of the molecular hydrogen laser is presented. The novel operation of the device to generate a fast-rising current pulse which travels down the discharge channel at the velocity of light is described. Finally, the experimental verification of lasing and further characteristics of the device are given.

higher laser frequencies, and a method for extending co-herent sources into the vacuum ultraviolet region ($\lambda < 2000$ Å), is described in this paper.

Proceedings of the IEEE, vol. 59, no. 4, pp. 679-684, April 1971., doi: 10.1109/PROC.1971.8235

FREE ELECTRON LASER

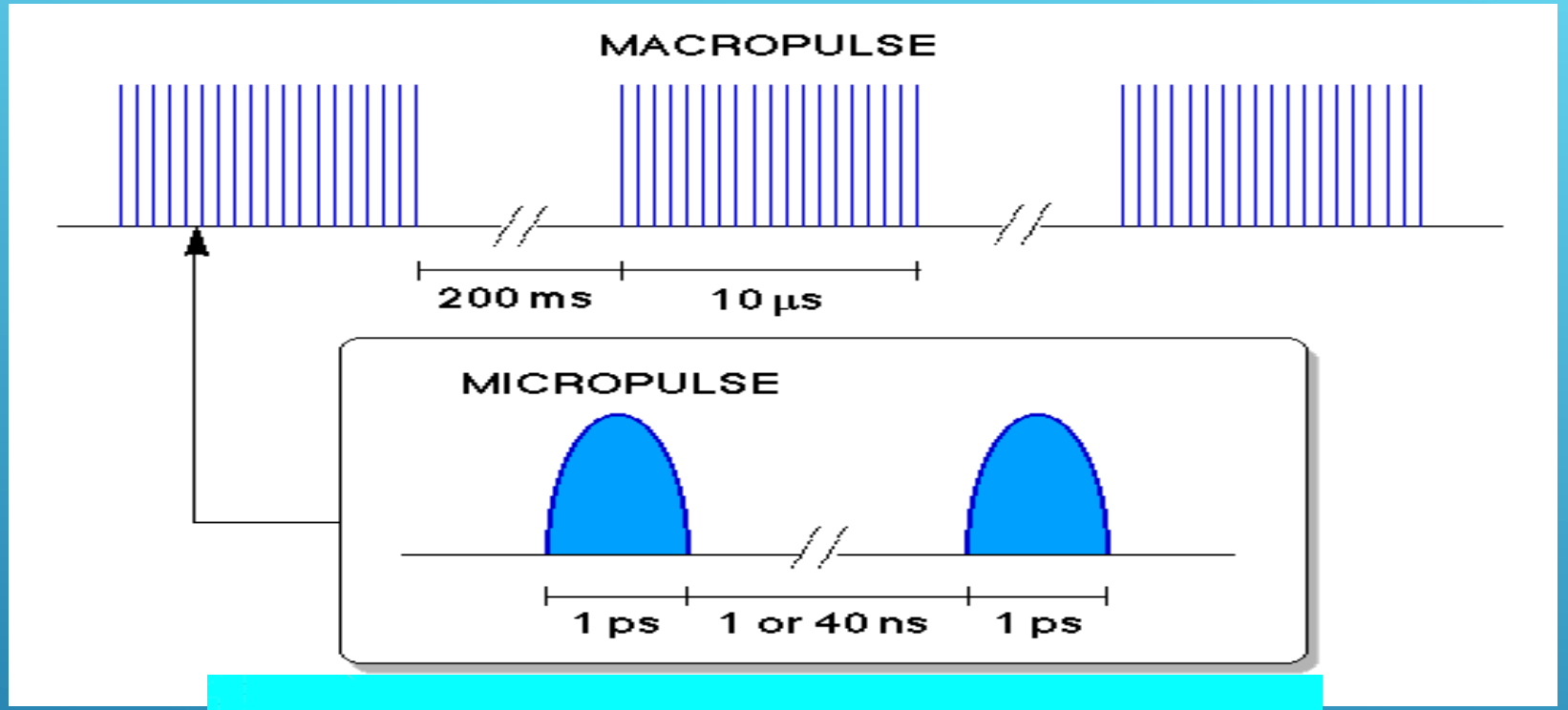
FEL LAYOUT

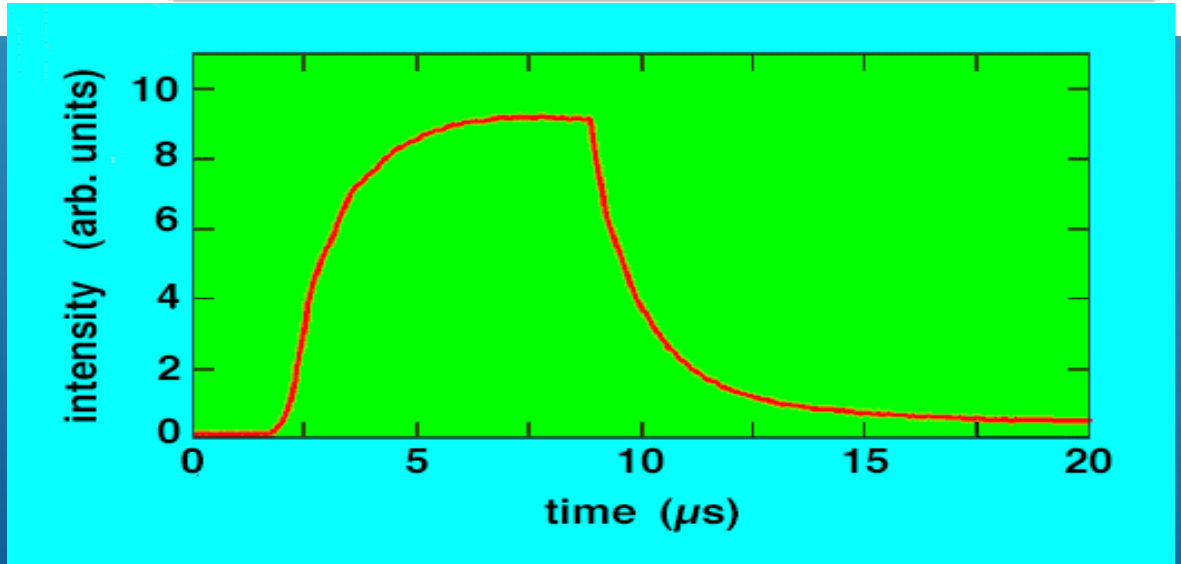


A beam of free electrons is accelerated **in a vacuum** in a device called **electron accelerator**.

Since these free electrons are not attached to any material (they are free …), they are **not limited to specific energy transitions of the atoms or molecules**. Thus, they can **emit radiation at any wavelength**.

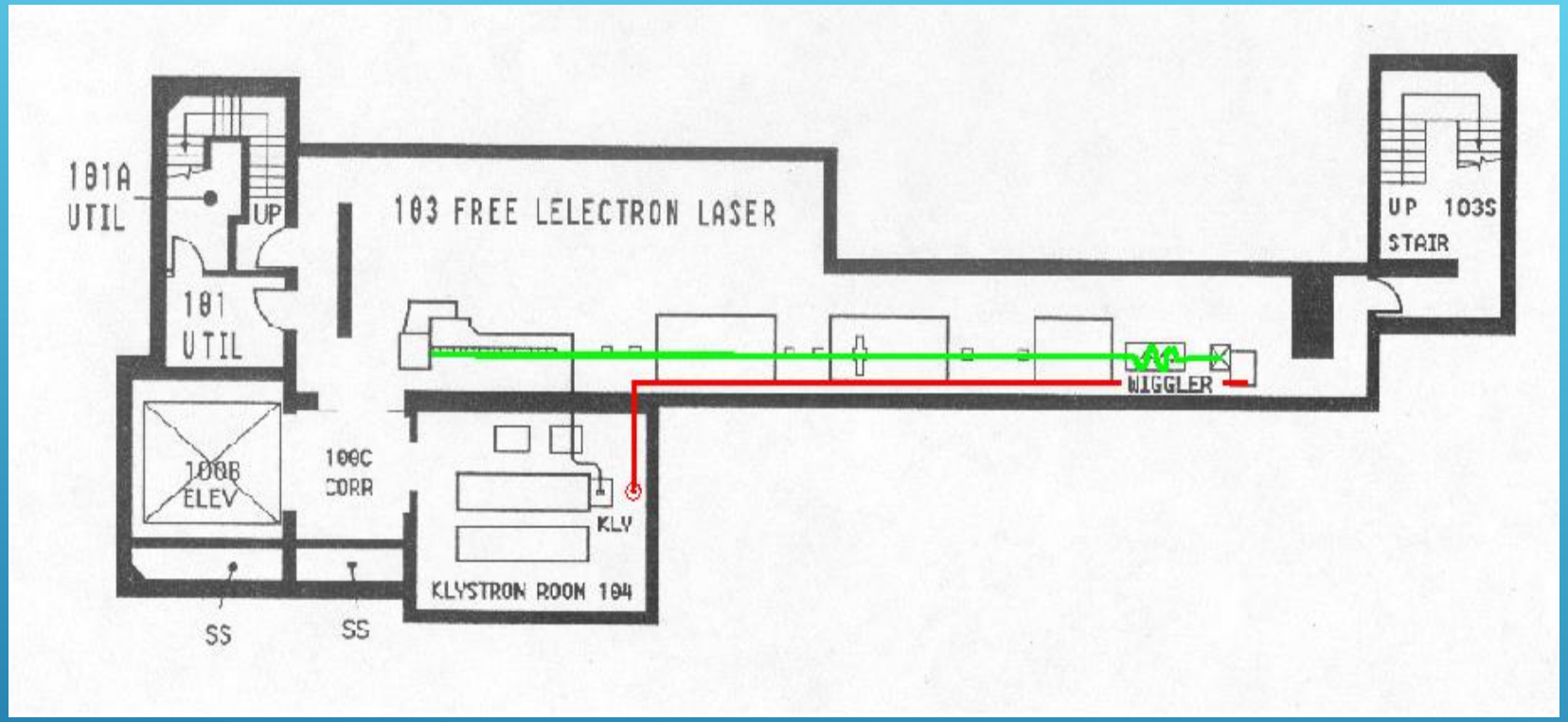
FEL PULSE


MACROPULSE
200 ms
10 μs
MICROPULSE
1 ps
1 or 40 ns
1 ps


intensity (arb. units)
0
2
4
6
8
10
0
5
10
15
20
time (μs)

W. M. KECK FOUNDATION FREE ELECTRON LASER CENTER

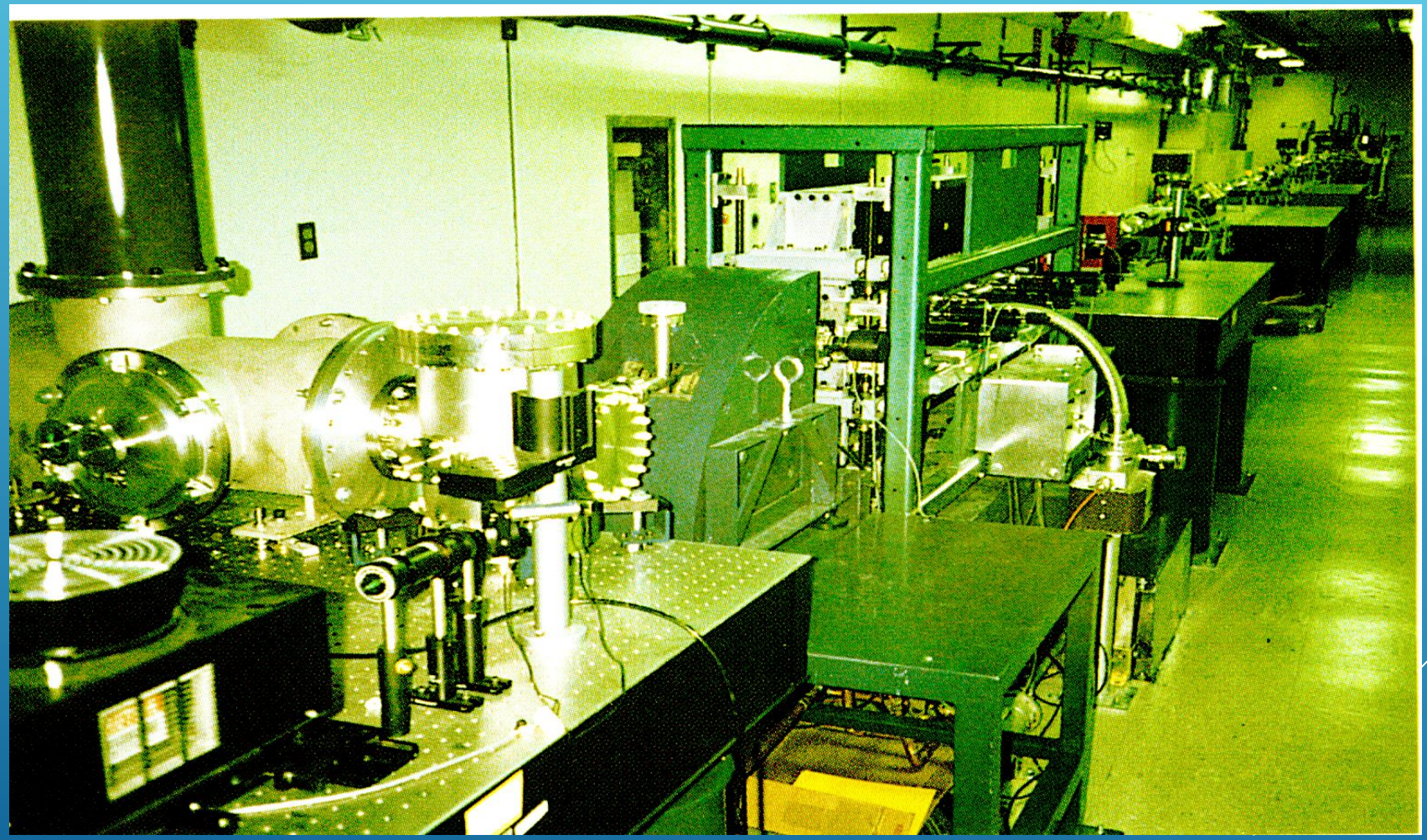
Vanderbilt University

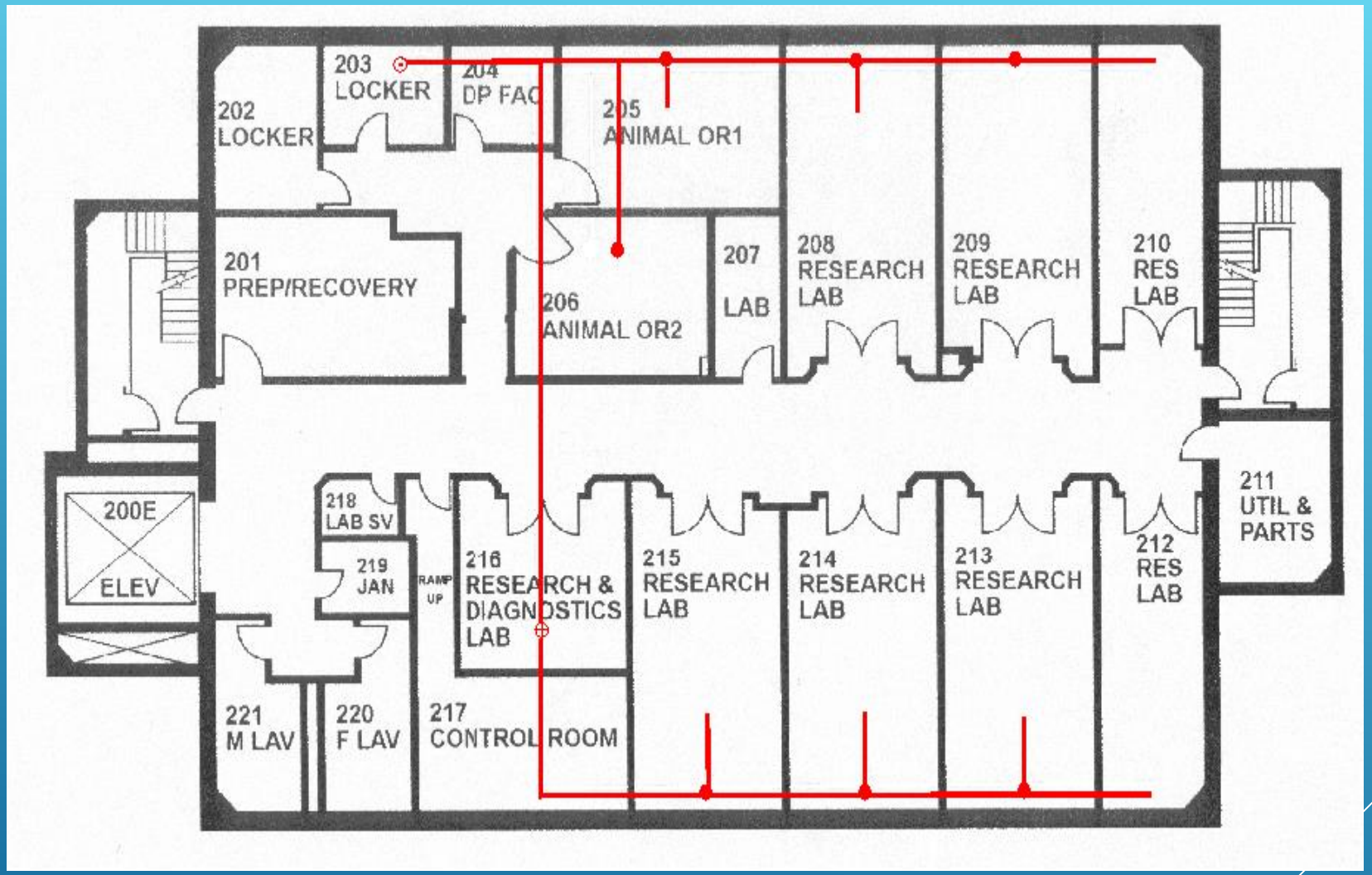


First Floor: FEL level

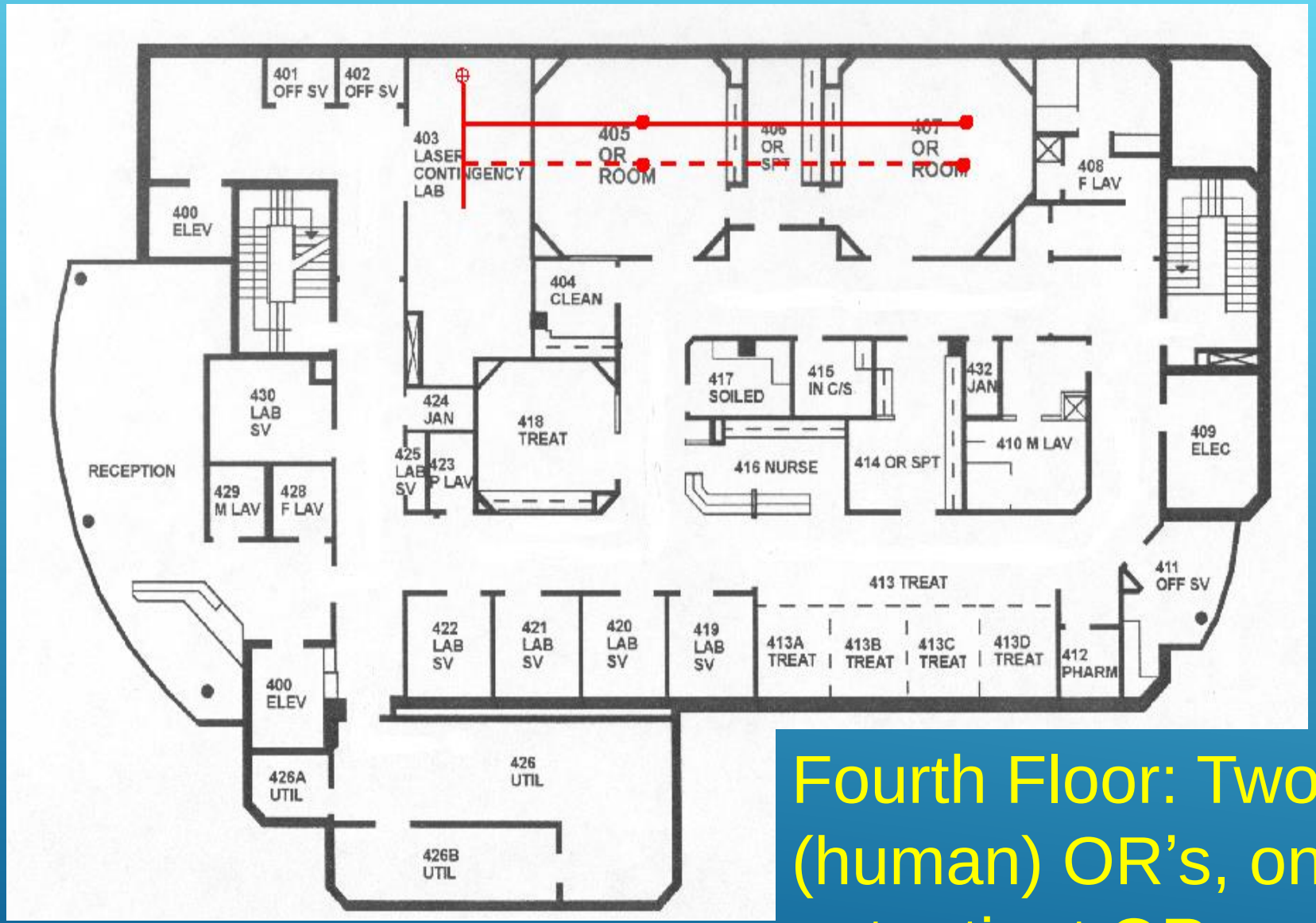
Fl1.tif

VANDERBILT FEL



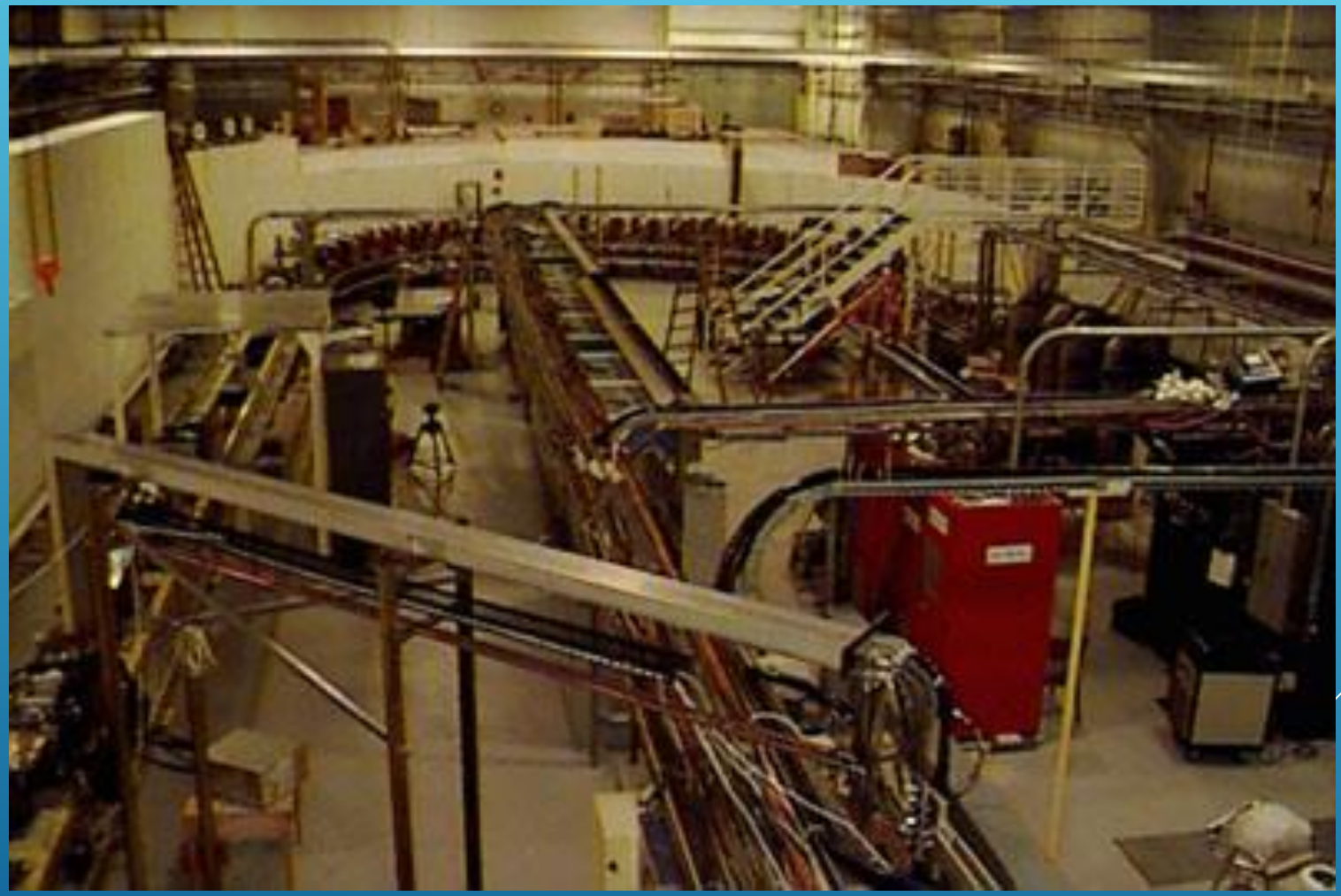


Second Floor: Animal OR and Research Space



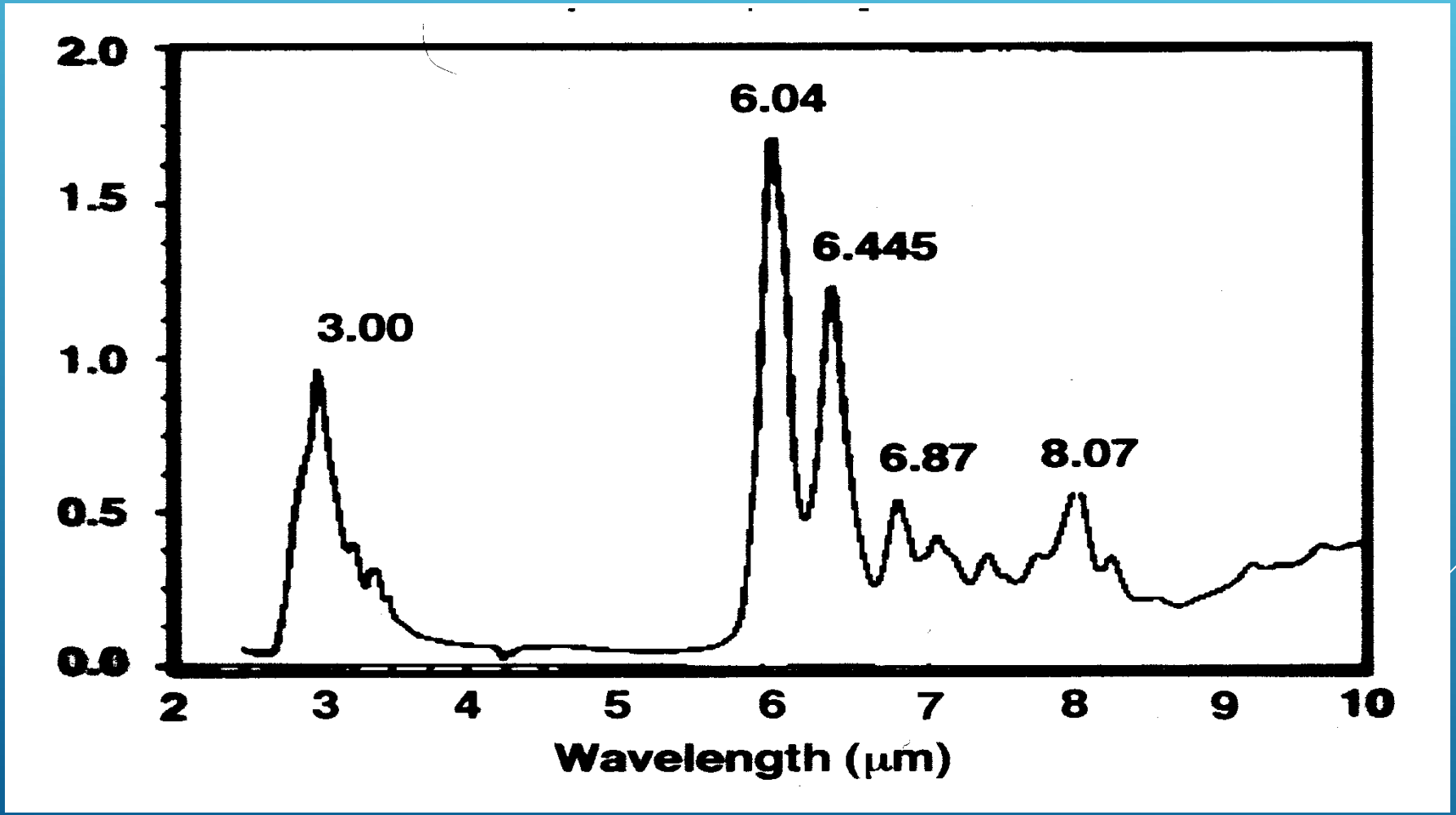
Fourth Floor: Two (human) OR's, one outpatient OR

DUKE FEL ACCELERATOR



EDWARDS, G., LOGAN, R., COPELAND, M., REINISCH, L., DAVIDSON, J., JOHNSON, B., . . . AL, E. (1994). TISSUE ABLATION BY A FREE-ELECTRON LASER TUNED TO THE AMIDE II BAND. *NATURE, 371*(6496), 416-9.

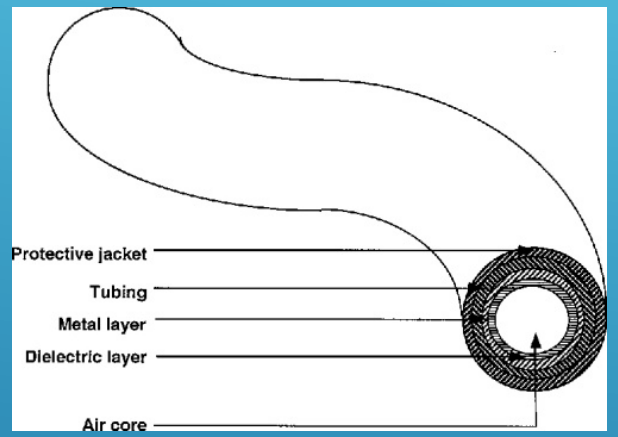
ABSORPTION SPECTRA OF DRY COLLAGEN FILM

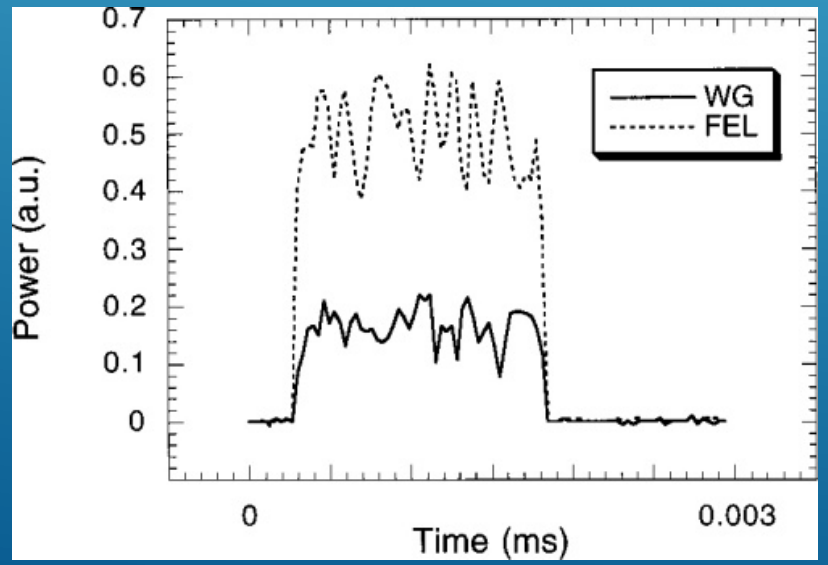


INFRARED WAVELENGTHS TESTED WITH THE FEL AND THE CORRESPONDING MOLECULAR ABSORPTION BANDS

Wavelength (μm)	Protein absorption band
6.1	Amide I (C–N–H)
6.45	Amide II (C–N–H)
6.8	C–H bend of CH_2 or CH_3
7.0	COO^- asymmetry stretch
7.2	C–H bend of C–CH_3
7.4	C–H bend of O=C–CH_3
7.5	Control flanking region
7.6	C–C–C stretch
7.7	Amide III (C–N–H)
8.0	Control flanking region
8.1	C–N stretch
8.6	(CH_3)CH–stretch
10.6	CO_2 laser control

I. GANNOT, R. WAYNANT, A. INBERG, AND N. CROITORU, "BROADBAND FLEXIBLE WAVEGUIDES FOR FREE-ELECTRON LASER RADIATION," APPL. OPT. 36, 6289-6293 (1997).

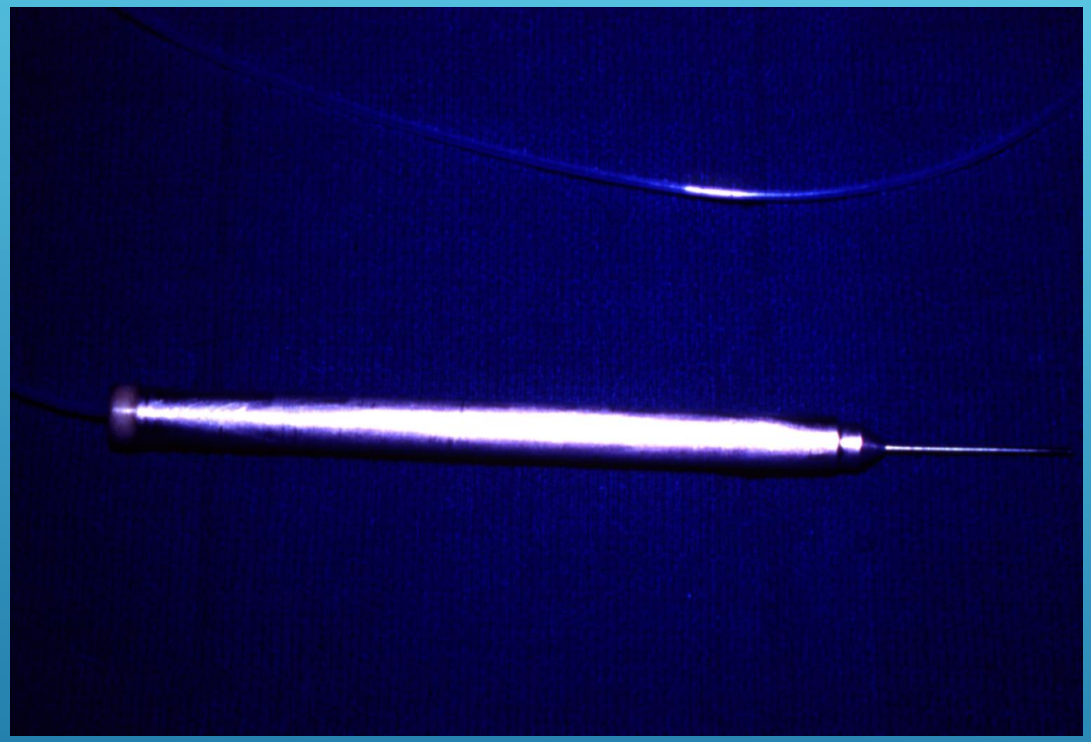


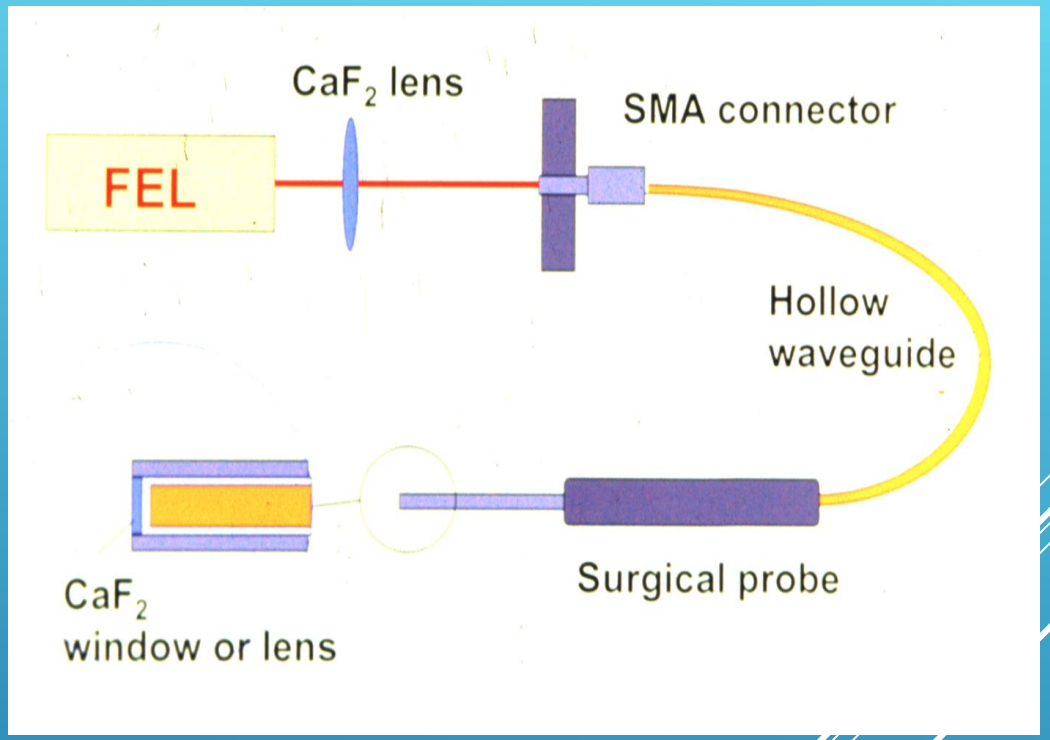


Abstract

We refined flexible waveguides previously developed for CO2 and Er:YAG laser radiation to transmit free-electron-laser (FEL) radiation. One can tune this laser over several segments of the radiation spectrum. This laser has a high peak power of as much as 10 MW with pulse energy of as much as 100 mJ. We made the waveguides of either Teflon or fused-silica tubes internally coated with metal and dielectric layers. We optimized the internal coatings specifications for transmission of various radiation wavelengths in the mid-IR range and enabled transmission of high-peak radiation. We performed experiments in three major FEL sites in the United States over a more than 1-year period when we measured and examined various characteristics of transmission. We used the analysis of these experiments as feedback to further improve these waveguides. The good preliminary results encourage us to invest more effort to further develop these waveguides until a suitable waveguide is obtained for this type of laser and make possible its introduction to the medical field where its characteristics can be exploited in surgical applications.

Ophthalmology Probe

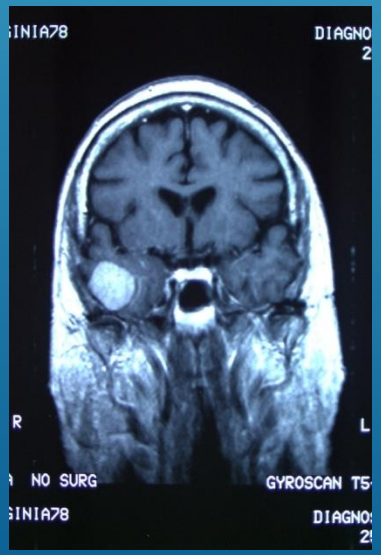


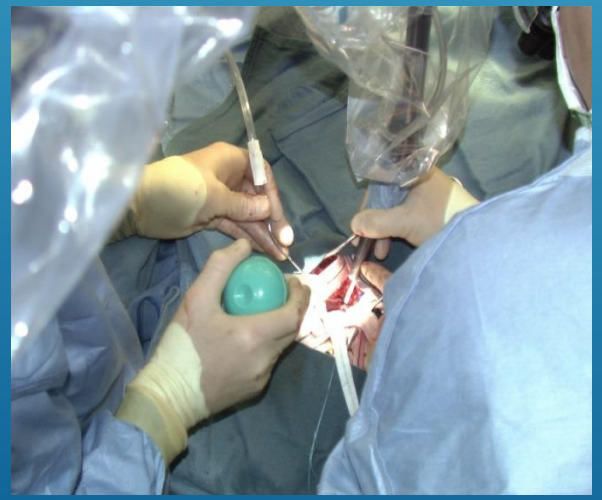


Joos, Karen M., et al. "Optic nerve sheath fenestration with a novel wavelength produced by the free electron laser (FEL)." *Lasers in surgery and medicine* 27.3 (2000): 191-205.

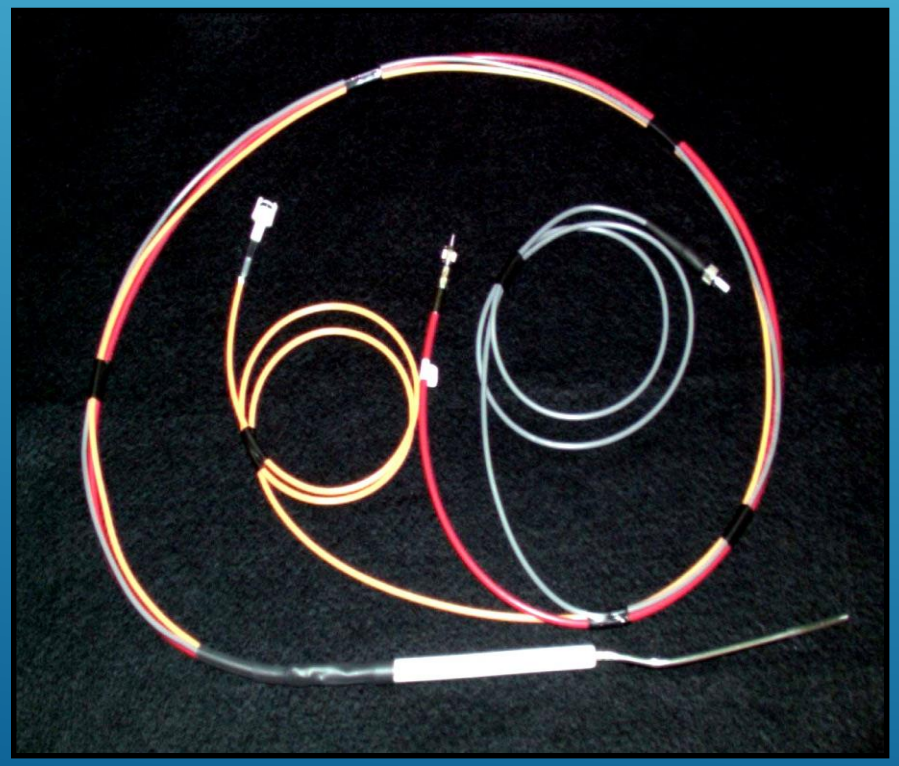
Neurosurgery, Tumor resection

- First ever human surgery with an FEL December 17, 1999.
- Benign meningioma tumor near right temple
- Unqualified success
- First step in long term program





Neurosurgical Probe-Hollow waveguide




US AIRWAYS

Mid–infrared laser applications in medicine and biology

Ronald W. Waynant, Ilko K. Ilev, Israel Gannot
Phil. Trans. R. Soc. Lond. A 2001 359 635-644; DOI: 10.1098/rsta.2000.0747. Published 15 March 2001

Ron’s Way

- (1986 – 2011): U.S. Food and Drug Administration (FDA)
- FDA’s Optical Therapeutics and Medical Nanophotonics Lab
- Ron’s Way
  - intelligence in a broad range of knowledge and expertize
  - remarkable intuition for challenging and unresolved topics
  - unconventional ideas and solutions
  - inspiration for his students and colleagues
  - relax and noble personality

Ron's Impact on the Development of Photobiomodulation and Photobiomodulation Therapy

- Ron played a seminal role in defining light-tissue interaction mechanisms and the development of Photobiomodulation (PBM) and its therapeutic applications (PBMT)

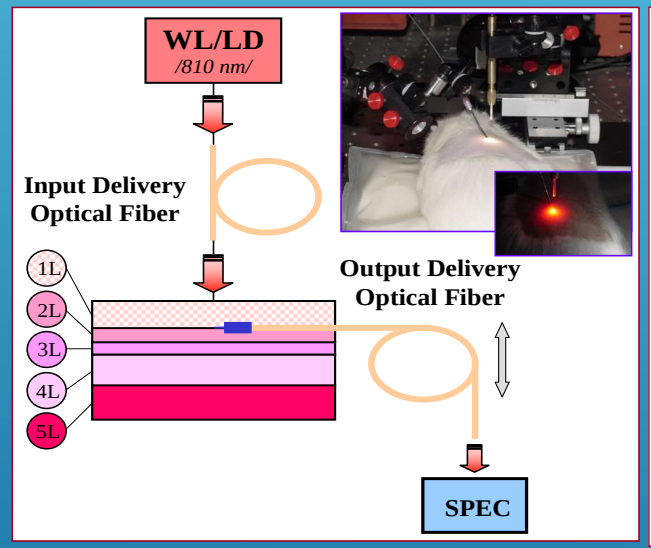
- Ron was instrumental in the adoption of the term Photobiomodulation in the field of Biophotonics
- In 2002, as part of the DARPA Program, a meeting was held at Uniformed Services University and a consensus was reached for the exclusive use of the term Photobiomodulation (Committee Members: Drs. Ronald Waynant, Ilko Ilev, Tiina Karu and Juanita Anders)

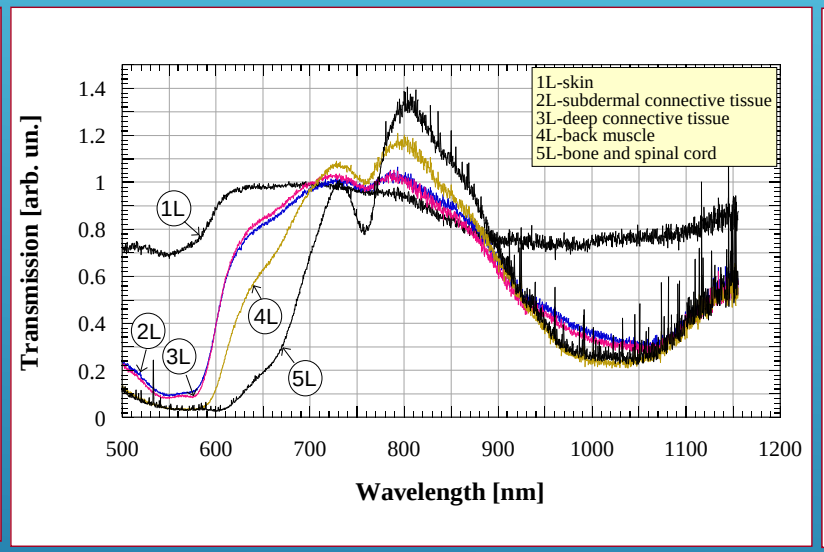
Ron's Impact on International Societies Promoting the Field of Photobiomodulation and Photobiomodulation Therapy

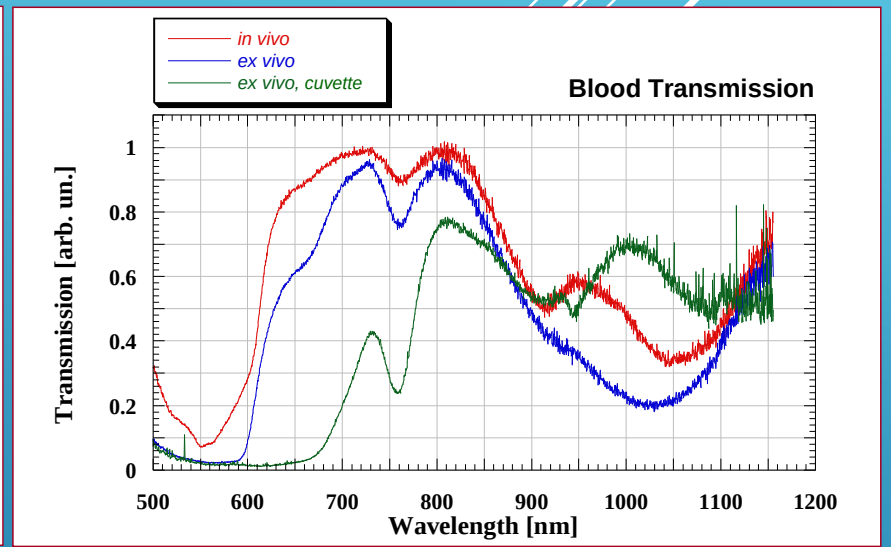
- He was a founding member of the North American Association for Laser Therapy (NAALT) organizing the NAAT inaugural meeting, which was held in FDA
- He organized and co-chaired a series of Engineering Conference International (ECI) Conferences on "Light Activated Tissue Regeneration" that introduced PBM to many researchers and clinicians who joined the efforts to understand the mechanisms of PBM and translate this knowledge into effective clinical applications
- Beginning in 2006, he co-chaired the Mechanisms for Low Light Therapy Conference at SPIE BiOS Photonics West
- These conferences were critical in understanding the effects of unresolved laser parameters on cellular response, therapeutic effect, and the underlying mechanisms
- Ron was named a Fellow of IEEE, The American Institute of Medical and Biological Engineers (AIMBE), The Optical Society of America (OSA), and The American Society for Laser Surgery and Medicine (ASLSM)

Ron guided and mentored many researchers and conducted carefully controlled studies of critical PBM parameters

- PBM topics researched in Waynant, Ilev and Anders collaboration: Broadband light penetration into deep tissues







- The highest penetration depth through all tissue layers overlying the spinal cord between the 770 and 850 nm wavelengths with a peak at 810 nm
- The 810 nm wavelength was minimally absorbed by blood and water
- These data demonstrated that 810 nm wavelength light is within the optimal range for light penetration to tissues deep in the body

PBM topics researched in Waynant, Ilev and Anders collaboration

- The effect of PBM on cutaneous wound healing in a diabetic animal model
- The effect of PBM on immune response, gene expression, and nerve regeneration
- The effect of light on human fibroblasts using fiber-optic nanoprobes
- Light supports proliferation and differentiation of human neural progenitor cells eliminating the need to add extrinsic growth and differentiation factors.

Ilev I.K., R.W. Waynant, K. R. Byrnes and J.J. Anders (2002) Dual-confocal fiber-optic method for absolute measurement of refractive index and thickness of optically transparent media. Optics Letters, 27:1693-1695.

Ilev I.K., R.W.Waynant, K.R. Byrnes and J.J. Anders (2003) On-off laser delivery into a precise tissue area using smart tissue-activated fiber probes. IEEE Journal of Selected Topics of Quantum Electronics, 9:331-337.

Byrnes, KR, L. Barna, V. M. Chenault, R. W. Waynant, I.K. Ilev, L. Longo, C. Miracco, B. Johnson, J.J. Anders (2004) Photobiomodulation improves cutaneous wound healing in an animal model of type II diabetes. Photomed. Laser Surg., 22: 281-290.

Ilev, I.K., R.W. Waynant, K. Byrnes and J.J. Anders (2004) A fiber-optic approach for *in vivo* minimally-invasive study of tissue optical properties, SPIE: 5317: 147-150.

Byrnes, KR, R.W. Waynant, I.K. Ilev, X. Wu, L. Barna, K. Smith, R. Heckert, Heather Gerst and J.J. Anders. (2005) Light promotes regeneration and functional recovery and alters the immune response after spinal cord injury. Lasers Surg. Med., 36: 171-185.

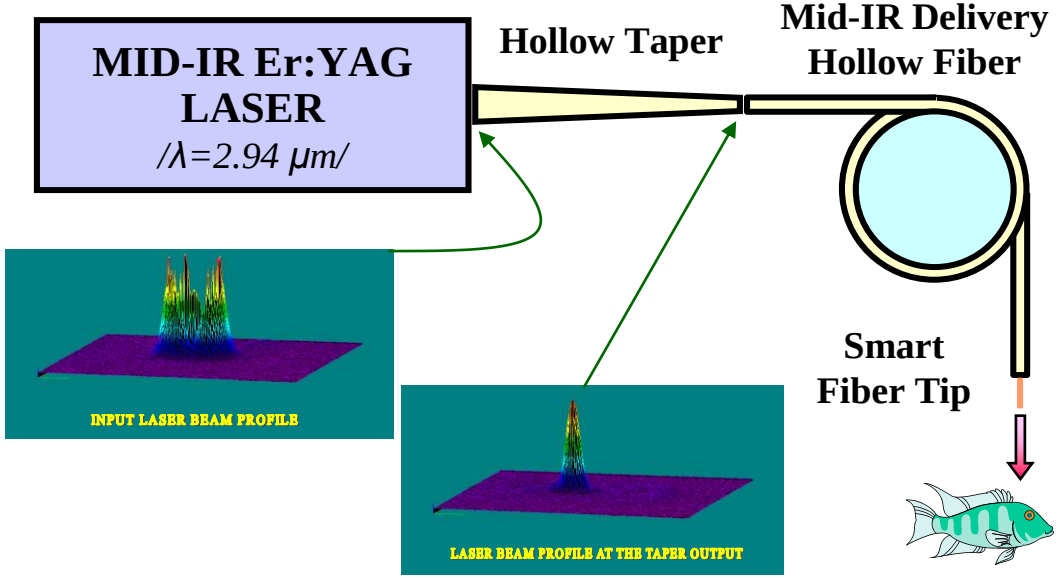
Byrnes, KR, X. Wu, R.W. Waynant, I.K. Ilev, and J.J. Anders (2005) Low power laser irradiation alters gene expression of olfactory ensheathing cells *in vitro*. Lasers Surg. Med., 37:161-171. Gopalendu, P., A. Dutta , K. Mitra, M. S. Grace, A.Amat, T. B. Romanczyk, X. Wu, K. Chakrabarti, J. J. Anders, E.Gorman, R. W. Waynant, Darrell B.Tata (2007) Effect of low intensity laser interaction with human skin fibroblast cells using fiber-optic nano-probes. J. Photochem. and Photobiol. B: Biology, 86: 252-261.

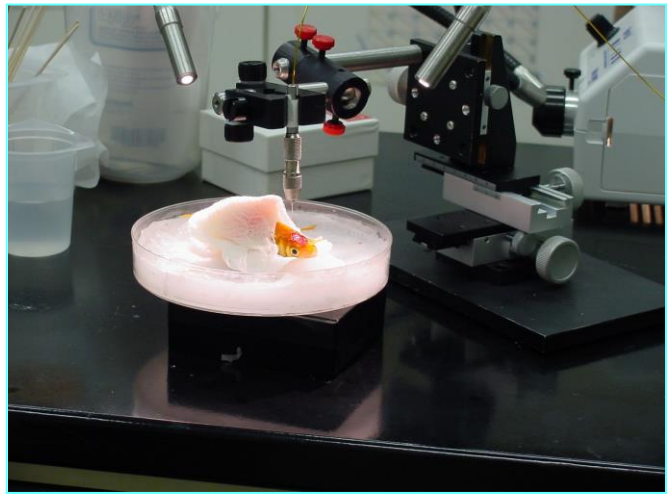
Dutta, A., K. Mitra, M. S. Grace, R. W. Waynant, D. B.Tata, E.Gorman, and J.J. Anders (2007) Analysis of biomodulaive effects of low intensity laser on human skin fibroblast cells using fiber-optic nano-probes. Proceedings of SPIE: 6428, 64280D-1.

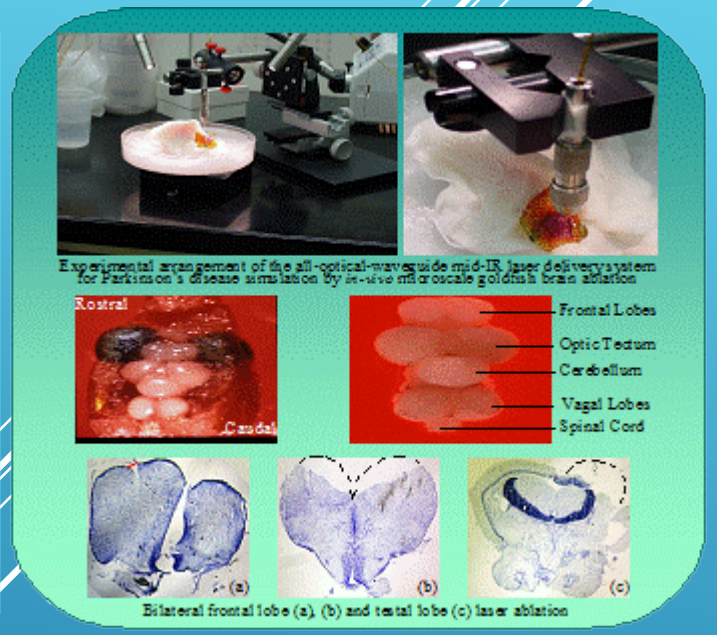
Anders, J.J, T. B. Romanczyk, Ilko K.Ilev, H. Moges, L. Longo, X. Wu, and R. W. Waynant (2008) Light supports neurite outgrowth of human neural progenitor cells in vitro: the role of p2y receptors. IEEE Journal of selected Topics in Quantum Electronics, 14(1): 118-125.

Anders, J.J., H. Moges, X. Wu, I. Ilev, R. Waynant, and L. Longo (2010) The Combination of Light and Stem Cell Therapies: A novel approach in regenerative medicine. American Institute of Physics Proceedings, 1 226: 3-10. Laser Florence 2009, Editor L. Longo, AIP Conference Proceedings, Melville, NY

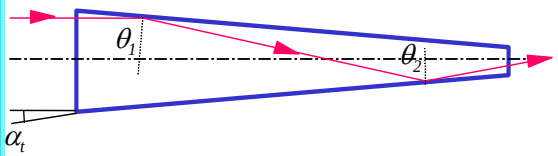
Unconventional Solutions: Optical Funnel and Smart Tissue-Activated Fiber Probes for On-The-Spot Goldfish Brain Ablation for Parkinson Disease Simulation



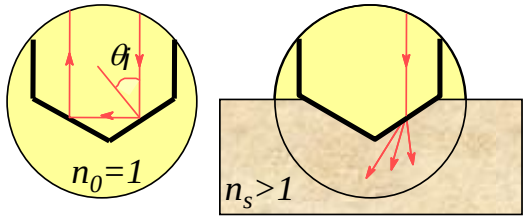




hollow taper/smart fiber principle



grazing-incidence uncoated hollow optical funnel

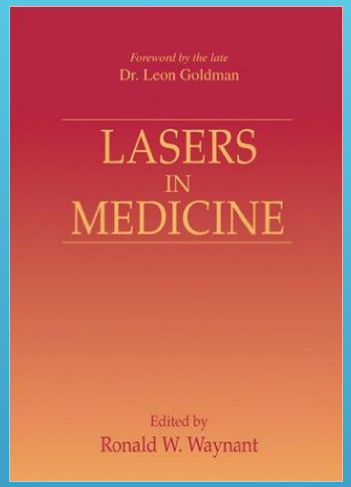


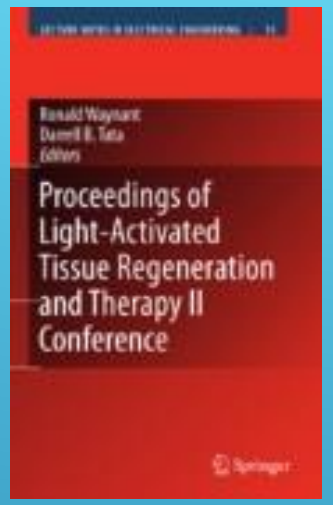
smart tissue-activated fiber tip

laser taper/fiber parameters

- Pulse Er:YAG, λ=2.94 μm
- 150 μm pulse duration, 20 mJ energy
- Pyrex-glass uncoated taper
- 2 mm/600 μm input/output diameter
- Mid-IR Hollow fiber
- 600 μm diameter, 600 mm length

- Ilev, Robinson, Waynant, Patent No. 7,787,106 (August 31, 2010)
- Ilev, Waynant, Gannot, Gandjbakhche, Patent No. 8,456,738 (June 4, 2013)
- Ilev, Waynant, Byrnes, Anders, IEEE JSTQE, 9, 331-336, 2003
- Ilev, Waynant, Ediger, Bonaguidi, IEEE JQE, 36, 944-948, 2000
- Ilev, Waynant, Applied Physics Letters, 74, 2921-2923, 1999
- Ilev, Waynant, Review of Scientific Instruments, 70, 2551-2554, 1999





Ron “was steadfast in his quest to unlock the mechanisms of laser tissue interactions and in his plea to scientists, clinicians, and industry to control and study parameters consistently and thoroughly. His relaxed character, good humor, and welcoming nature were truly infectious. He was loved by his colleagues, students, and friends alike.”

Raymond J. Lanzafame, MD, MBA, FACS Photomedicine and Laser Surgery Volume 34, Number 8, 2016 Pp. 309–310

RONALD WAYNANT'S CONTRIBUTIONS IN OPTICAL SCIENCES

Attended Johns Hopkins University, earning a Bachelor's in Engineering Science in 1962.

Ph.d. in CU in 1971 while working for Westinghouse (1962-1969)

1969-1986: the Naval Research Laboratory (69-86),

1986-2011: US FDA

Early Work: UV Lasers and Laser Sciences

Beam Divergence Measurement for &-Switched Ruby Lasers
R. W-. Waynant, J. H. Cullom, I. T. Basil, and G. D. Baldwin (Westinghouse)
Appl. Optics, Vol. 4, pp. 1648-1651, December 1965 (0.79 mrad beam)

VUV Laser emission from molecular hydrogen
R. W. Waynant, J. D. Shipman, Jr., R. C. Elton, and A. W. Ali, Appl. Phys. Lett. 17, 383 (1970).

OBSERVATIONS OF GAIN BY STIMULATED EMISSION IN THE WERNER BAND OF MOLECULAR HYDROGEN
RONALD W. WAYNANT, NAVAL RESEARCH LABORATORY, WASHINGTON, D. C. 20390
PHYS. REV. LETT. 28, 533 – PUBLISHED 28 FEBRUARY 1972

A discharge-pumped ArCl superfluorescent laser at 175.0 nm
Ronald W. Waynant
Naval Research Laboratory, Washington, D. C. 20375 (Received 22 November 1976)

R. W. Waynant, ***"XeF waveguide laser,"*** Opt. Lett. 3, 221-222 (1978)

TRANSITION: APPLICATIONS OF LASERS:

Application of a Scanned-Laser Active Imaging System to Atmospheric and Underwater Viewing Environments.
Descriptive Note : Interim rept.,
Corporate Author : NAVAL RESEARCH LAB WASHINGTON D C
Personal Author(s) : Waynant,Ronald W.

J. G. Eden and R. W. Waynant (NRL), "***Lifetime and collisional quenching measurements of XeF*(B) by photolysis of XeF2***," Opt. Lett. 2, 13-15 (1978)

Excimer lasers, their applications, and new frontiers in lasers
Authors:Waynant, R.W.
P1984-01-01
Conference: SPIE technical symposium, Arlington, VA, USA, 29 Apr 1984; Related Information: Volume 476
Publisher:
SPIE Society of Photo-Optical Instrumentation Engineers, Bellingham, WA

MEDICAL APPLICATION OF LASERS

Ronald W. Waynant (FDA);
Medical Applications Of Ultraviolet Lasers. Proc. SPIE 0894, Gas Laser Technology, 60 (July 12, 1988); doi:10.1117/12.944392.

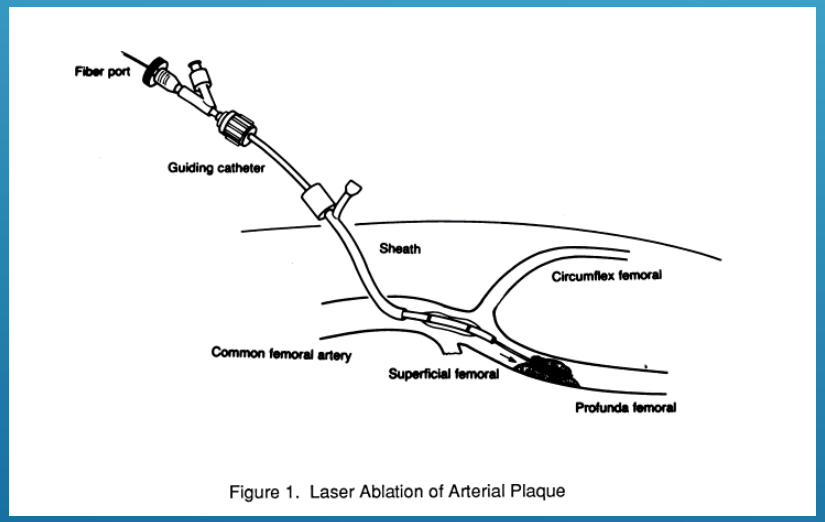


Figure 1. Laser Ablation of Arterial Plaque

Ocular keratotomy

The clean cutting available from the ultraviolet excimer lasers has triggered the possible use for corneal surgery. By resculpturing the cornea, which is a major

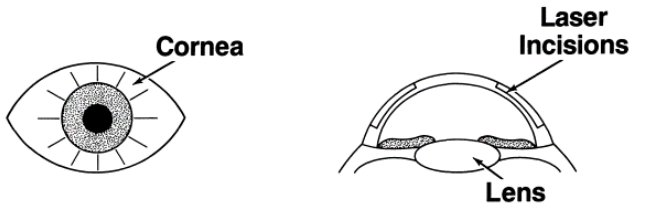


Figure 2a. Radial Keratotomy

Figure 2b. Sculpturing of the Cornea

Near IR Fiber-Optic Sensing and Imaging

Started to collaborate with him 2002, worked in his lab during the summer of 2003 and 2004.

Simple Confocal Microscopy Based on Single Hollow-Core Photonic Bandgap Fiber
Do-Hyun Kim, Jin U. Kang, **Ronald W. Waynant**, Ilko K. Ilev,, OSA Technical Digest, CLEO 2006, CMR1

Surface Enhanced Raman Glucose Detection Using Gold Nanoshells
Hyun Youk, Jin U. Kang, Jacob Khurgin, Anant Agrawal, Ilko Ilev, **Ronald Waynant**, OSA Technical Digest, CLEO 2006, CMH5

An all-fiber optic confocal interference microscope using low-coherence near infrared light source
Do-Hyun Kim, **Ronald Waynant**, Ilko K. Ilev, Jin U. Kang, JTuA51, OSA Technical Digest, CLEO, 2007

Upconversion fiber-optic confocal microscopy using a near-infrared light source
Do-Hyun Kim, Jin U. Kang, ***Ronald W. Waynant***, Ilko K Ilev, CTuF6, OSA Technical Digest, CLEO 2007

Discussion on perspectives and mechanisms of laser phototherapy in the dinner-meeting organized by DARPA in 15th Annual Meeting of IEEE Laser and Electro-Optic Society in Glasgow (Scotland) Nov. 11, 2002. M. Dyson (U.K., second from the left), R. Waynant (USA) and T.Karu (Russia) in the center.

THANKS RON FOR YOUR MENTORING, KNOWLEDGE AND FRIENDSHIP.

WE MISS YOU VERY MUCH!

ISRAEL GANNOT, ILKO ILEV, JUANITA ANDERS AND JIN KANG