

## 1. 学歴

- 1969年 3月 大阪大学 工学部電気工学科 卒業  
1971年 3月 大阪大学 大学院工学研究科電気工学専攻修士課程 修了  
1977年 9月 東京大学 理学博士

## 2. 職歴

- 1971年 4月 日本電子株式会社 開発本部  
1976年 5月 上智大学 理工学部物理学科 助手  
1981年 5月 電気通信大学 新形レーザー研究センター 助教授  
1990年 3月 電気通信大学 新形レーザー研究センター 教授  
1990年 5月 電気通信大学 レーザー極限技術研究センター 教授  
1999年 4月 電気通信大学レーザー新世代研究センター 教授  
2011年 4月 電気通信大学 名誉教授  
　　電気通信大学 企画調査室 特任教授 (研究戦略アドバイザー)  
　　浜松ホトニクス 顧問  
2012年 4月 大阪大学 レーザーエネルギー学研究センター 特任教授  
2013年 5月 Leading Scientist, Mega Grant Program, Russian Federation of Ministry of Education  
and Science, "Novel Optical Materials for Advanced Lasers"  
2014年 4月1日 公益財団法人 豊田理化学研究所 客員フェロー

- 1995- Member of Joint Open Laboratory on Laser Crystals and Precise Measurements, The Russian Academy of Sciences
- 1996- 日本オプトメカトロニクス協会フォトンテクノロジー技術部会 部会長
- 1997-2002 Topical Editor of Applied Optics, Optical Society of America
- 1998-2000 応用物理学会 理事
- 1999-2002 Board of Director, Optical Society of America
- 2000-2001 経済企画庁 世界における知的活動拠点研究会 委員
- 2000 OSA Fellow
- 2000-2004 物理系学術誌刊行協会 理事
- 2002-2004 新エネルギー・産業技術総合開発機構 産業技術審議委員会&機械工業技術戦略研究会委員 レーザー学会 理事
- 2002-2011 Chair of Steering Committee of CLEO Pacific Rim  
Co-chair of Japan Joint Council of Quantum Electronics
- 2002-2004 International Member of Review Committee of Canadian Institute of Photonic Innovation, Canada
- 2002-2005 Secretary of IUPAP C17 (Quantum Electronics)
- 2003- Member of ICUIL (Working group of IUPAP) (International Committee on Ultra Intense Laser)
- 2003-2017 日本学術会議 連携会員 (19期、20期、21期、22期)
- 2003-2005 日本学術会議 物理学研究連絡委員会 幹事  
国際物理年WG 委員
- 2004 文部科学省 光・光量子科学技術の指針方策に関する検討会 委員
- 2004-2013 Editor in Chief, Optical Review  
日本光学会 常任幹事
- 2005-2008 Chair of IUPAP C17 (Quantum Electronics)
- 2005- General Co-Chair and Promoter of International Symposium of Laser Ceramics  
Editor of Laser Physics Letters
- 2006 Co-Editor of JOSA B, special topics on fiber lasers  
IPAP (Institute of Pure and Applied Physics) 理事
- 2006- 文部科学省 「X線自由電子レーザー利用推進協議会」委員
- 2006-2010 日本物理学会 理事 (2期)
- 2007 Chair of Asian Intense Laser Network  
応用物理学会フェロー
- 文部科学省 光科学の推進方策懇談会 委員
- 2008- Member of IUPAP WG on Communication in Physics
- 2008-2011 Chair of ICQE (International Council on Quantum Electronics)
- 2009 文部科学大臣表彰科学技術賞（研究部門）「セラミックレーザーの研究」
- 2009- 日本学術会議科学者委員会学術誌問題検討分科会 委員  
天田金属加工財団 理事
- 2009-2011 レーザー学会 副会長
- 2009 JOSA-B Special Editor on a Focus Issue (the 50th anniversary of the first operating laser)

- 2011 紫綬褒章（物理学）
- 2011-2013 Member of Frederic Ives Medal/Quinn Prize committee, OSA
- 2011- 日本国学術会議連携会員（22期） 平成29年まで6年間  
物性物理学・一般物理学分科会、IUPAP 分科会、ICO 分科会、  
国際サイエンスデータ分科会、デバイス・電子機器工学分科会委員
- 2012-2013 日本学術振興会国際企画委員会 委員 理工学分野 副部長
- 2012- 日本学術会議科学者委員会学術誌問題検討分科会 幹事  
応用物理学会 光・量子エレクトロニクス賞（宅間 宏賞）選考委員長  
Member of Quantum Electronics Award Committee, EPS
- 2013- 文部科学省独立行政法人評価委員会 科学技術・学術分科会 日本学術振興  
会部会 委員（部会長）
- 2013-2015 Leading Scientist of Russian Mega Grant Program on «Creation of the  
Laboratory of diagnostics of novel optical materials for advanced lasers».

## 1) 大出力電子ビーム励起 KrF レーザーの研究

レーザー核融合を実現するためには、レーザー・プラズマ相互作用において、異常吸収→高速電子の発生を抑制し、低温のまま燃料を爆縮するために、短波長、紫外域の高出力レーザーが必要となる。1980年当時、実用炉用に想定されたレーザーは24ビームで10MJを発生できるレーザーであり、最終段増幅器のKrFレーザーは500kJを効率10%で発生する必要があった。KrFエキシマの結合-自由状態遷移を利用するので、電子ビーム励起で生成した上準位分布のすべてがレーザー発振に寄与できるため、

248nmという短波長ながら高効率、高出力レーザーとなる潜在力を持っている。

しかし、実際には、数100keV-1.5MeVの相対論的エネルギーをもつ電子ビームを1.5-3気圧の気体中に打ち込み、多種多様な励起状態、イオン状態を作り出しながら、それらの間の激しい2体反応、3体反応の結果であるので、ナノ秒の励起寿命を持った中間状態が多数関係する。これらの反応断面積、脱励起速度の解析、計測を通じて、反応ダイナミックスを明らかにする基礎研究を行った。

500kV、400kA、パルス幅100nsの相対論的電子ビーム発生装置を開発し、MW/ccの高密度励起で10倍高い利得条件を実現しながら、将来の核融合用KrFレーザーの実験的シミュ

レーションを行った。30x30x100cmの増幅器体積から、出力600J、電子ビームエネルギーからKrFレーザー出力への変換効率10%を達成した。10倍の励起密度のレーザーを用いた研究により、反応ダイナミックス、レーザー増幅器の物理拡大則から、将来の核融合用レーザー増幅器600kJレーザーが効率10%で動作可能であることを実験的に示した。KrFレーザーはASE限界動作を行うレーザーであり、米国のように巨大なレーザーを実際に作らなくても、本質的な動作限界は物理の拡大則を活用することで見事に実証された。その間、巨大なレーザー増幅器を用いながら、強力なレーザー光による誘導放出が生み出す新たな脱励起チャンネルを利用する反応動力学研究を行った。レーザー利得媒質の中の反応素過程を外部制御できることから、従来とは全く異なる手法による反応素過程研究が可能であった。吸収係数の精密測定のために、コンスタント利得計測法を開発したが、その結果、極端な利得飽和を発生させ、強力な励起エネルギーを注入するレーザー増幅器中で、実効利得がゼロ、または負という条件も実現することができた。このように小信号利得から完全飽和、利得ゼロからマイナスまで、レーザー増幅器の飽和過程の全履歴を実験的に検証した実験は他に例を見ない。



図 1:電子ビーム励起 KrF レーザー増幅器

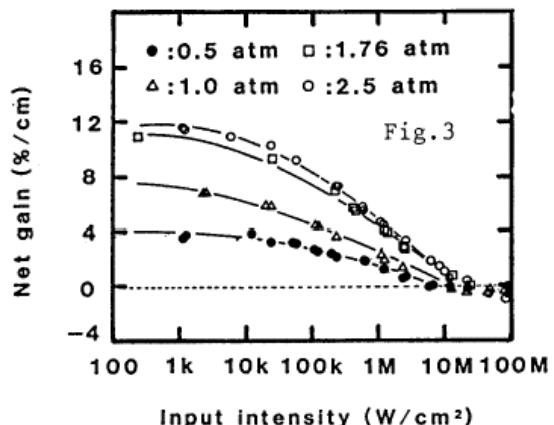


図 2:小信号から負利得まで

## 2) 高性能光学薄膜の研究

核融合用高出力レーザーや重力波検出用超高安定化レーザーも、その最終限界を決めているものは、光学素子の表面に形成された光学薄膜である。レーザー損傷強度や薄膜の散乱、吸収損失がレーザーの到達できる限界性能を決定する。高耐力ミラーや超高反射率、超低損失薄膜の開発を行った。光音響計測法（PAS）、光誘起電流計測法などの開発により、光学薄膜内の微小吸収から電子雪崩に至る損傷機構を解明し、フッ化物による2次電子生成抑制効果、レーザーアニール効果などを発見した。誰も想像しなかったフッ化物光学薄膜の開発により、レーザー損傷強度を5倍に増大することに成功した。光学薄膜の高耐力化はレーザー增幅器の高効率化につながり、大きな波及効果を發揮した。

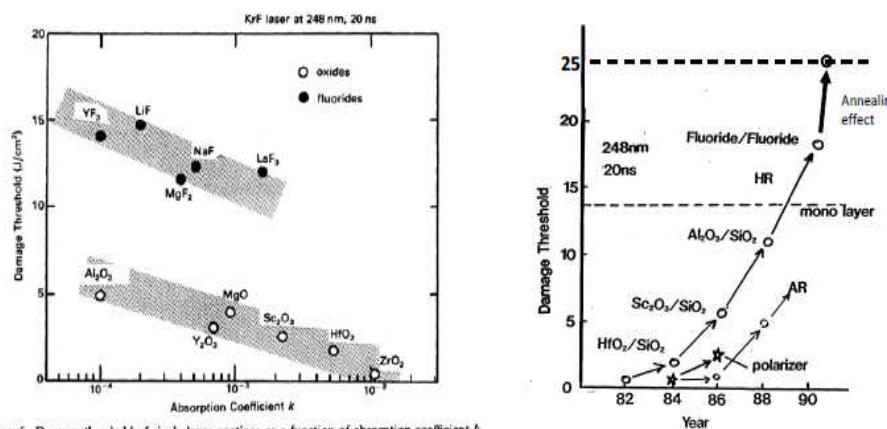


FIGURE 6. Damage threshold of single layer coatings as a function of absorption coefficient  $k$ .

図 3: 吸收係数とレーザー損傷強度の相関と国産ミラーの品質改善

超高安定化レーザーの周波数制御の基準は超高反射ミラーで構成された基準共振器に蓄積した自身の過去の平均値を参照する。また重力波アンテナ自身、巨大な多重レーザー干渉計であるので、そのミラーは日本で生産されたことのない量子限界性能が求められた。米国ではジャイロ品質ミラーと呼ばれる PPM 損失ミラーの開発に取り組み、我が国の光学メーカーと高性能光学薄膜研究会を組織した。超平滑面研磨、イオンビームスパッタリング薄膜技術の開発と同時に、サブ・ヘルツまで周波数安定化したレーザーを用いたフィネス計測、リングダウン法、周波数応答関数計測法、居新規内光散乱計測法などを開発して、我が国の高性能光学薄膜技術を確立した。今では共振器内光子寿命が数10マイクロ秒を超えるミラーも製作可能で、Cavity Enhancement 技術などが発達し、高次高調波発生、コンプトン散乱実験などに不可欠の光学素子となっている。

### 重力波天文学と連携した国産超高品质ミラーの進歩 超平滑研磨+IBSコーティング(高性能光学薄膜研究会の成果)

	1992	1994	1995	1996
反射率	99.97 %	99.9905 %	99.8596 %	99.9867 %
透過率		37 ppm	1399 ppm	1318 ppm
損失		58 ppm	6 ppm	1.5 ppm
共振器 透過率	0.014 %	15.2 %	99.1 %	97.6 %
フィネス	5,908	39,000	2,236	23,560

光共振器の透過率  $\eta_T$  は  $T/A$  で決まる。  
超高品质ミラーとは、高反射率を意味しない。  
超低損失ミラーでなくてはならない。  
コンプトン散乱などの光共振器などの問題も共通課題。

$$\eta_T = \left( \frac{T}{A+T} \right)^2$$

損失が決める

図 4: 超高反射率光学ミラー：開発の歴史と  
低損失の重要性

### 3) 重力波検出用超高安定化レーザーの研究

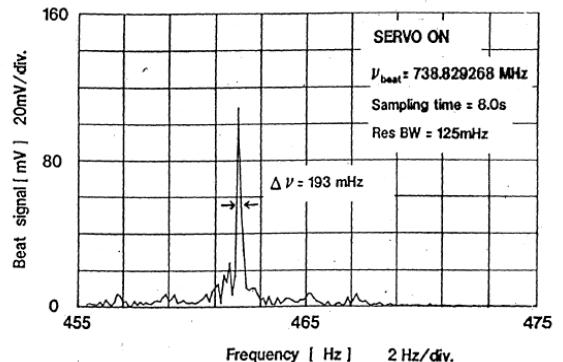
重力は自然界の基本的な力であり、人類の日常を支配しているが、同時に未解明の分野が極めて大きい。一般相対論が予測する重力波は、パルサー計測などによる間接的証明がされているとはいえ、重力波の直接観測は最も測定困難な課題として物理学の前に存在している。現在、神岡に建設中の大型重力波アンテナ KAGRA の研究も 1991 年から始まった重点領域研究が出発点である。植田は重点領域研究の計画研究当時から、超高安定化レーザー、超高品质ミラー開発の責任者として重力波天文学に参加し、光源、光学素子開発に従事してきた。図 5: レーザー周波数の安定化による 193mHz ビート線幅

上原昇君ら電通大の優れた学生の協力で安定化レーザーの開発に成功し、我が国の重力波研究を軌道に乗せることができた。

また、前述の光学素子開発の成果もあって、国立天文台の 20m アンテナ、300m の TAMA300 の成果を経て、現在、長さ 3km、全地下方式、大型低温重力波アンテナ KAGRA の建設につながった。従来のレーザー技術の常識を捨てたところから始まった量子限界超高安定化レーザーの研究は、レーザーの本質を考える良い機会となり、その後の高出力ファイバーレーザーやセラミックレーザーの研究の出発点を与える結果を生み出した。重力波の直接検出ができるても、人類の生活にはなんの変化もない。しかし、最も役に立たない純粹 科学研究である重力波検出用レーザーの開発は、産業用レーザーの主力となつたキロワット出力ファイバーレーザーや、レーザー核融合を可能とする透明セラミックレーザーにつながつたのである。

重力波天文学の広がりは更に拡大し、今では宇宙重力波天文台計画 DECIGO も進行中である。いずれの重力波アンテナにあっても、超高安定化レーザーと超高品质光学素子が鍵となる技術で、これらの研究は絶えることなく進展している。

193-mHz beat linewidth was measured directly in the air.



#### 4) 高出力ファイバーレーザーの研究

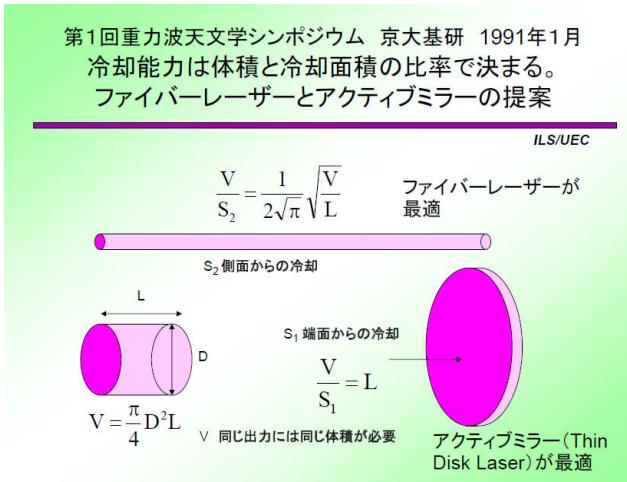


図 7:冷却拡大則：ファイバーレーザーと Thin Disk Laser に高出力レーザーとしての潜在力がある。

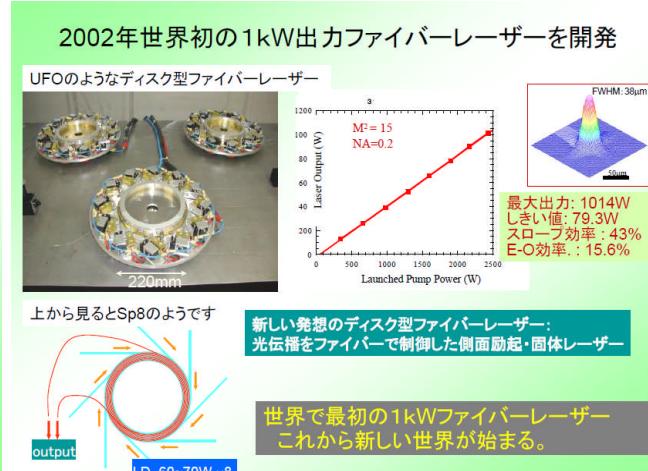


図 6:UFO のような形をしたファイバーから作ったディスクレーザーで世界最初の 1kW 出力を実現

1990 年台なかばまでファイバーレーザー増幅器とはファイバー光通信の信号増幅器を意味しており、高出力レーザーとの関連はなかった。重力波検出用レーザー研究の過程で空間モード制御の重要性とともに、冷却拡大則を提案する中でファイバーレーザーに高出力レーザーとしての潜在力があることを指摘する事になった。HOYA、浜松ホトニクスなど、ファイバー、半導体レーザー技術のある民間企業の協力を得て、産業用高出力ファイバーレーザーの開発を行った。ファイバーを素材としたディスク型レーザーというユニークなアイデアも生み出し、2002 年には単一ファイバーから 1kW を発生するファイバーレーザーの開発に世界ではじめて成功した。

今では産業用高出力レーザーの主役は、明らかにファイバーレーザーと Thin Disk Laser となっているが、その基本は単純な物理の拡大則(冷却拡大則)にある。

#### 5) 完全透明セラミックレーザーの研究

人類にとって長い歴史を持つセラミック（土器、磁器）であるが、我々が研究始めた当時、その定義の中に不透明が入っていた。結晶とそれ以外の状態が混在して存在するセラミックでは、異なった屈折率を持った物質が混在しているため、半透明なもののはりえても、透明セラミックはないと言われていた。しかし、1991 年頃、高温炉用の窓材として開発されたセラミック YAG を目に入れた植田はセラミックの散乱損失を極限まで減少させればレーザー材料に使用可能な透明セラミックが可能だと考えた。神島化学の協力を得て、完全透明セラミックの開発に着手し、A. Kaminskii 教授と共に、レーザー結晶作製技術や結晶分光学の知識を応用して、完全透明セラミックを開発することに成功した。セラミックレーザーは結晶レーザーの分光学的、機械的、熱的性質を維持しながら、ガラスレーザーと同様の大口径大型レーザー材料の大量、安価な生産に道を開く技術として、固体レーザーに革命をもたらしている。セラミックレーザーとは多結晶体であるが、そのグレンン境界層は 1-2Å と極薄で、光散乱、フォノン散乱に影響をあたえることはない。むしろ単結晶育成中に発生するファセット、内部応力分布などに起因する散乱損失、屈折率不均一などが存在しないため、単結晶レーザーより効率、出力とも優れていることを実証した。

さらに、単結晶育成が困難な高融点結晶 ( $\text{Y}_2\text{O}_3$ ,  $\text{Sc}_2\text{O}_3$ ,  $\text{Lu}_2\text{O}_3$ ) などのレーザー材料開発にも道を開くこととなった。

これらの成果は世界的にも高く評価され、国内外の大型レーザー計画はセラミックレーザーを用いることになった。中でも、米国は植田らが発表した論文の体系的追試を行う特別研究を国立研究所、民間企業に命じ、1000 個のサンプルを配布してその真偽を確かめた。



図 9:ガラスと結晶の利点を併せ持つセラミックレーザー

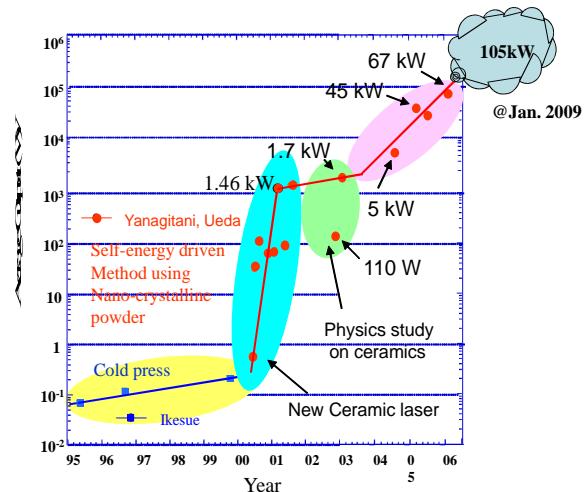


図 8:高出力セラミックレーザーの進歩

その結果、植田らの研究結果の全ては正しく、まさしく完全透明セラミックを用いたセラミックレーザーは新時代の固体レーザーであると認め、大出力レーザーの開発計画の中心を、従来の化学レーザーから電気レーザー、すなわち電池駆動半導体レーザー励起セラミックレーザーに変更することとなった。実際、米国の 3 研究機関で平行して 100kW セラミックレーザー開発が進められ、いずれも予定通りの高出力レーザーの開発に成功し、現在 MW 平均出力レーザーの開発が進められている。

レーザー核融合の将来計画でも、欧州共同プロジェクト HiPER や日本の将来計画が Yb:YAG セラミックレーザーを採用するなど、ガラスレーザーの最大の問題であった大出力レーザーの高繰り返し動作の問題を解決する切り札を与えている。

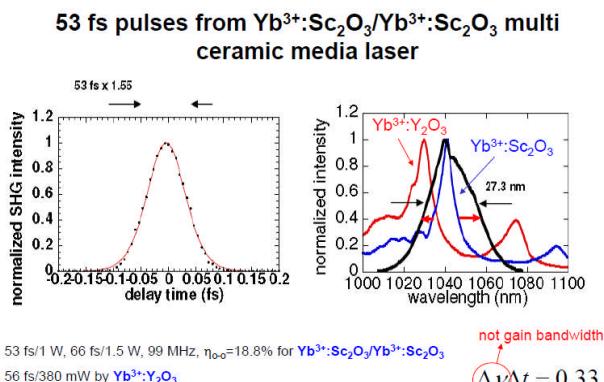


図 10:マルチセラミックレーザーを使ったバンド幅を超える超短パルス

Lasing spectrum is broader than gain bandwidth  
in deep modulation regime of phase locking.

Optics Express, 17, 3353 (2009)

高出力レーザーのもう一つの最前線は、超短パルス超高ピークパワーレーザーである。この分野でもセラミックレーザーは従来の結晶レーザーの限界を打ち破る技術として期待されている。超短パルス発生には広帯域利得が必要で、一方、高利得を生み出すには狭帯域で大きな誘導放出断面積が必要という矛盾を固体レーザーは持っている。従来は広帯域で誘導放出断面積の小さなレーザー材料（チタン・サファイア）などを強力な固体レーザーの第2高調波で励起して用いていたが、効率は極めて低くなる。本当の応用、例えばレーザープラズマ加速や真空の非線形などの研究を行おうとすれば、高繰り返しで長時間の運転が必要で、高効率レーザーでなくては純粹科学的研究といえども、実現不可能となる。そこで、新しいレーザー材料の開発が必要となり、セラミックレーザーの潜在力に期待がかかっている。

異なった蛍光スペクトルを持ったセラミック材料を重ねると、誘導放出断面積を減少することなく広帯域を実現することができる。ちょうど、ガラスレーザーの発光スペクトルが広がっているように、人工的に不均一広がりを創りだすことで、超短パルスを発生させようとした。 $\text{Yb:Y}_2\text{O}_3$  と  $\text{Yb:Sc}_2\text{O}_3$  の2種類のセラミックレーザーを重ねることで、53fsというYb添加固体レーザーとしての最短パルス幅を達成した。これらの研究の過程で、これらのレーザー材料そのものの非線形屈折率を活用したKLM（カーレンズモードロック）方式を開発し、KLMによる深い変調による位相同期条件で、自己位相変調によるスペクトル広がりが顕著となり、従来、理論的限界と考えられていた発光スペクトル幅を超える帯域を活用した超短パルス発生が可能なことを発見した。半導体レーザーで直接励起できる超短パルスレーザーの発展は超高出力レーザーの将来に不可欠で、将来を切り開く新しいレーザー材料、レーザー物理を目指して研究を進めている。

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