

# Lasers: reminiscing and speculating

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Perspective



It is almost 50 years to the day when  
**Charles Townes,**  
**Alexander Prokhorov and**  
**Nikolay Basov**  
received the Nobel Prize for their work providing the scientific basis  
for the laser.



## Their comments in their Nobel Addresses

**Townes** – “solve a puzzle, understand something new, and its exhilarating”

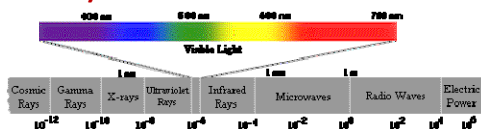
**Prokhorov** – “many believed that we had gone crazy, that it was impossible”

**Basov** – “opened up vast new macroscopic and microscopic horizons”

Since then 20 Nobel Laureates have been honored for laser enabled research. Evidently Townes', Prokhorov's and Basov's outstanding contribution provided a means to amazing new fields of science.

## A bit of history

You might think optics started when someone in Greece figured out the law of reflection (**Archimedes about 212 BC**).



You might think **Newton** kick started it in the late 1600s when he separated white light into colors and couldn't make a color reform white light.

He also made the Newtonian telescope and Newton's rings and Devised the corpuscular theory of light.

But, in **1803 Thomas Young** performed the double slit experiment proving that light was wavelike. Developed gratings and a means to measure wavelength.

The experimental foundation for Maxwell's theory.

~**1814 Augustin-Jean Fresnel** required light be wavelike.



# The last ~50 years or ~1/4 the history of modern optics

Some of us, myself included, have been contemporaneous with this piece of history and **so has the laser and nonlinear optics**.

- Either I have been very lucky or have lived very long.
- I would like to think I chose to work in a very exciting field.

It is worth noting that **James Clerk Maxwell** anticipated nonlinear optics when he wrote the polarization of a medium as a power series expansion in powers of the electric field. Then he dropped the terms of order higher than 1 since they would be too small.

He was right but he was also wrong.



## Laser Pre-history

1916 – **Albert Einstein** realized the roles of spontaneous and stimulated emission.

- ~1900 **Henri Becquerel** had observed spectral line narrowing while studying the 694 nm emission from ruby. Made note of it in his notebook but did nothing about it.

1939 – **Valentin Fabrikant** proposed using stimulated emission to amplify light but did not pursue the idea.

1939 – I was born

1951 – **Charles Townes** proposed isolating excited ammonia in a resonant cavity so that stimulated emission could amplify at microwave frequencies.

- 1954 - Together with **James Gordon**, his student, Townes demonstrated the MASER.

1958 – **Charles Townes** and **Arthur Schawlow** (Townes' brother-in-law) published "Infrared and optical masers," in the December 15, 1958 *Physical Review*.

- *This paper was to serve as the blueprint for laser science.*



## The patent fight

Gordon Gould was 37, an elderly graduate student of Polykarp Kusch at Columbia University.

On November 13, 1957 he took his notebook to a notary public and had his description of a Fabry-Perot resonator with a gain medium within notarized.

Gould discussed his idea with a patent attorney and developed an extensive list of possible gain media but neither he nor Townes and Schawlow were close to building one.

Gould left Columbia and went to work for TRG, Inc. and worked out a deal to share patent rights with the company.

Gould had to bring patent infringement suits against laser manufacturers and he won. The thirty year **patent war ended in 1985**. Gould was issued forty-eight patents including **optical pumping, collisional pumping, and applications patents** being the most important.

## Laser history begins

### **In 1960 Theodore “Ted” Maiman**

did what no one else expected - he used a pulsed flash lamp to excite lightly doped ruby.

- He silver coated both ends of a stubby ruby rod, scraped a small hole in the center of the silver at one end to serve as the output coupler and on May 16, 1960 demonstrated the first LASER.
- This took place at the Hughes Research Labs in Malibu, California.



## How could Maiman prove lasing?

Keep in mind that most of the diagnostics that we have today did not exist in 1960.

Maiman had to show:

1. Threshold
2. Spectral narrowing
3. Relaxation oscillations
4. Collimated beam

He did all of this and his paper was rejected by **Samuel Goudsmit**, editor of Physical Review Letters because there had been too many papers with the word Maser in the title.

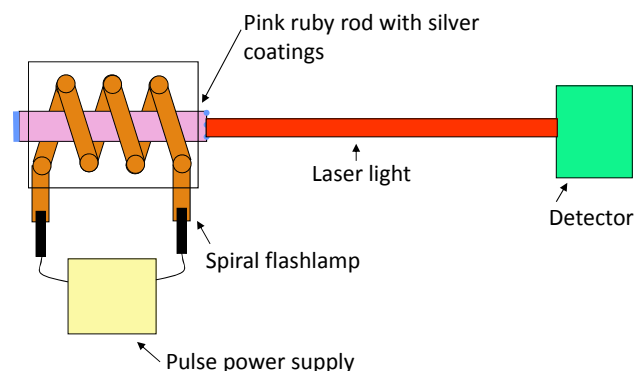
Maiman had entitled his paper "**Optical Maser Action in Ruby**" – the word Laser had been coined by Gordon Gould in his not yet revealed notebook entry for his patent.

With that Hughes organized a press conference to announce the first laser and Maiman sent a note to Nature.

## The Maiman laser

Because all lasers are essentially the same ever since:

In the 1960s I would give talks in which I would first define the acronym **LASER as Light Amplification by Stimulated Emission of Radiation** and then describe a laser as having three components – **a means to excite** the second component, **a medium that when excited could amplify light** and a third component, **a resonator** that could bounce the light back and forth many times to use the amplifier many times.



## Then the dam burst

- ❖ **Theodore Maiman** at Hughes Res. Labs. - **Ruby** - 1960
- ❖ **Ali Javan** at Bell Laboratories - **HeNe** - 1960
- ❖ **Elias Snitzer** at American Optical – **Glass and fiber** – 1961
- ❖ **Robert Hall** at General Electric Research Laboratories – **Diode** – 1962
- ❖ **Kumar Patel** at Bell Laboratories - **Carbon Dioxide** - 1964
- ❖ **Joseph Geusic** at Bell Laboratories – **Nd:YAG** – 1964
- ❖ **George Pimentel** at U.C.-Berkeley – **Chemical** - 1965
- ❖ **Peter Sorokin** at IBM Watson Laboratories – **Dye** – 1966
- ❖ **Nikolai Basov** at the Lebedev Physical Institute – **Excimer** - 1970

## An early application of the ruby laser

In the 1960s while people joked about the laser being a **SOLUTION IN SEARCH OF A PROBLEM** a problem was found.

(don't laugh – this is very major laser materials processing and without it there would be some very unhappy people)

### **drilling holes in baby bottle nipples**

How else would you make the holes that the baby can suck on and the pressure relief holes that allow the formula to keep flowing.



## Something to notice

All but one of these new lasers were demonstrated by researchers in industry laboratories.

- Most likely because they could re-direct efforts more easily than could academics.
- Most likely because they had mixes of engineers and physicists.
- Most likely because they had materials scientists.
- Most likely because they had available equipment and supplies.

HOWEVER, something did happen at a university.

I started graduate school at the University of Michigan in the fall of 1960.

**Peter Franken** was the first year grad student advisor.

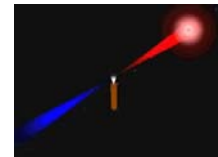
He had decided that there had to be a horse somewhere.



**The horse was nonlinear optics!!!**



## Second harmonic generation



Franken's idea was that lasers made the **electric field large** enough to make small terms detectable.

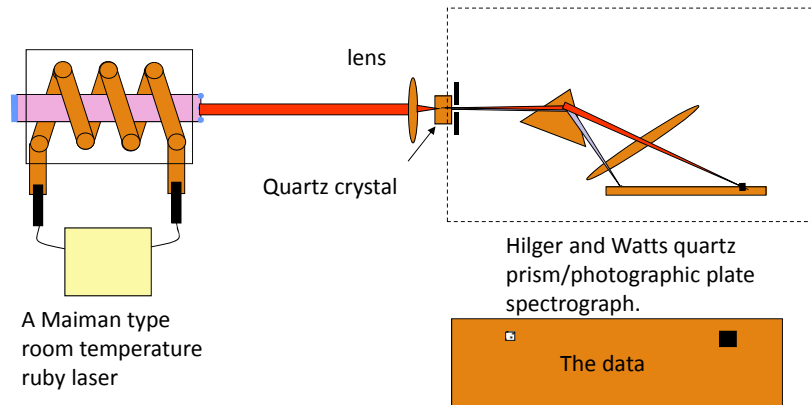
Weinreich pointed out that you had to have **non centro-symmetric media**.

Peters had the **spectrograph and the dark room**.

Allan Hill was a junior year physics student with **unusual experimental skills**.

- Besides, no graduate students were yet available and willing to take a risk on such a strange idea.

## The experiment (Spring 1961)



P. A. Franken, A. E. Hill, C. W. Peters and G. Weinreich, Phys. Rev. Letters, **7**, 118 (1961)

## My involvement

I saw Alan Hill using the laser and decided anything that could make that much light had to be worthy of study so I made Peter Franken a deal.

- If I could work with the laser I would be his student.
- To my amazement he agreed – I think he planned this from when I first met him.

My first experiment was to demonstrate **optical sum frequency generation** - 1962

- The light from two different lasers was made to add together to produce the sum of their two frequencies. Now common but was not then.

My next was to show **optical rectification** -1962

- This had to await the **invention of the Q-switch by Robert Hellwarth** to allow clean temporal pulses.
- I will receive the 2014 R. W. Wood Prize for this discovery since people now recognize its importance as a means to generate terahertz waves.

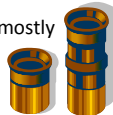
## Experimenting in the olden days

**There were no:** **Optical tables** (used granite slabs from gravestone companies and vacuum hold downs)



**Standard optical hardware** (Ealing bench hardware only fit on Ealing benches otherwise you made your own)

**Optical components** (most was military surplus – Edmunds Optical sold mostly surplus optics)



**Alignment lasers** (not yet invented) (you used an auto collimator)



**High speed detectors** (a few, very expensive photo diodes and photomultipliers with bandwidth up to about 1 GHz)

**CCD cameras or detectors** (you used photographic film, spectrographic plates or Polaroid film)

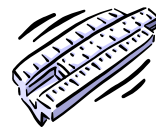


**High speed oscilloscopes and all were analogue** (a Tektronix 519 cost many dollars, had a few GHz bandwidth and required a signal of several volts to drive it. To record a scope trace you had to photograph it in real time usually with a scope camera and special Polaroid film.)



**Calibrated energy meters** (you were inventive – how many Gillettes could the laser burn through when focused with a certain lens?)

**Computers, not even hand calculators** (you used a slide rule)



## The ABDP paper – my small role

In 1962 there was no such thing as e-mail so I mailed **Jack Armstrong** at Harvard a preprint of the sum frequency paper.

- He glanced at it and, I am told, put it in his trash basket.
- **Nicolas Bloembergen** came in and saw it, having read the first second harmonic generation paper by Franken et al, and realized the importance of nonlinear optics.

The next morning Bloembergen gathered Armstrong, Pershan and Ducuing in his office and assigned them their parts in **the now famous Armstrong, Bloembergen, Ducuing and Pershan paper (ABDP) that set down the theoretical underpinnings of nonlinear optics.**

Bloembergen says that he had to work on the theory because he didn't have a laser and couldn't afford to buy one.

- This theory may have been a large part of his Nobel Prize.

Franken should have shared in a Nobel prize for nonlinear optics but had taken a position at DARPA and that probably made him not politically correct enough for the Swedish committee.

## Lasers at Berkeley

From 1964-1966 **Y-R Shen and I** were the only laser people in physics at UC Berkeley.

We were constantly being quizzed about these strange new devices. At one lunch, **Owen Chamberlain**, Nobel Laureate, kept us for 2 hours with questions about fields in resonators, coherent properties of light and optical gain.

To try to have some answer about coherence I forced myself to read **Roy Glauber's** papers on coherence from a quantum point of view. It was a great struggle but when I finally figured out that he was solving the two slit diffraction problem it all became clear(?). He won a Nobel prize for this.

## A curious side trip from an American Physical Society Meeting

In 1965 I attended an APS meeting at Caltech in Pasadena, California.

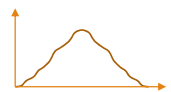
I ran into **John "Jan" Hall**, who had been my undergraduate lab instructor at Carnegie and who would win a Nobel Prize in 2005.

During a break we decided to visit the laser group at Hughes in Culver City and were shown a laser pulse with steps as it rose and fell.

We said nothing because neither of us realized this was mode locking and their detector-oscilloscope combination was too slow to properly detect it.

Mode locking, though mentioned, **L.E. Hargrove** et al had reported it in a HeNe laser in 1964, had not yet been widely discussed in the literature.

- **Anthony deMaria's** work was not published until 1966. That is when mode locking became exciting.



## Time in an industry lab - Raytheon

1966 -1973 at the Raytheon Research Division.

### New solid state and dye lasers, and laser damage research.

We worked with our materials science people seeking an alternative to Nd:YAG.

- We discovered, studied and patented the host yttrium ortho aluminate, YAP or YALO.
- ZnSe for infrared windows.

Dye laser theory with **Marvin Weber** containing a criterion for cw lasing.

- In 1970 **Ben Snavely** and **Otis Peterson** may have used it to make the first cw dye laser.

## Also at Raytheon

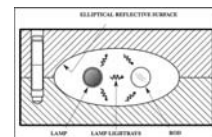
**Colin Bowness** patented the elliptical pump cavity 1965.

**Dave Whitehouse** built the first 1 kW CO<sub>2</sub>.

**Roy Paanen** built a 100 W argon ion laser.

**Pim Andringa** developed a passive method to prevent counter circulating beams in a laser gyroscope from locking.

I became involved in the optical properties of materials and introduced the concept of statistics to the laser damage community. We had to build our own lasers to do the experiments.



## Years at USC and at CREOL

I then spent 1973-1987 at the **University of Southern California** where I developed the Center for Laser Studies

- and had the pleasure of working with outstanding colleagues, students and post docs some of whom have won very prestigious awards, are fellows of major societies and chaired professors at major universities.

Since the committee asked me to reminisce about the early days I leave out the amazing events of my time at **CREOL, the College of Optics and Photonics**, now 27 years old, which rose from just 7 hardy souls to over 250 faculty, students, post docs, research scientists and staff and became the first U.S. College of Optics and Photonics in less than 15 years.

## Where are these lasers now?

The **ruby** laser is a historical footnote.

You can still buy a **HeNe** laser but visible diode lasers are cheaper, more rugged and more colorful.

The **diode** laser is the most widely used laser of all. **It is so important that it gets its own slides.**

**Fiber** lasers of many kilowatt outputs are now available for industrial applications. Fiber lasers also generate short pulses (sub pico-second). **Er doped fiber amplifiers** make fiber communication possible.

The **CO<sub>2</sub>** laser can produce very high average power outputs (multi kW) and is a reliable tool in manufacturing.

The **Nd:YAG** laser with diode laser pump sources can be very small, light weight, and rugged and in other configurations very powerful for industrial and military applications.

**Dye** lasers were very important in short pulse studies were messy and sometimes dangerous. OPO's and tunable solid state lasers replaced dye lasers as tunable light sources.

**Chemical** lasers have dangerous exhausts but may be useful in certain military applications.

**Excimer** lasers are very important in surgery (LASIK) and some materials processing.

## Diode lasers and a modern miracle

A miracle is something that happens that is unexpected and seemingly inexplicable.

The diode laser was first demonstrated in 1962 .

- It required cooling to LN2 temperature and lasted just a few minutes.

Meanwhile at the University of Michigan, **Wilbur Peters** had been experimenting with fiber optics.

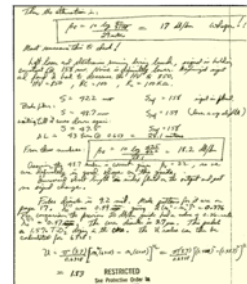
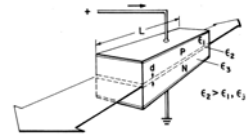
At Corning, Inc. they were finishing work on Corningware and were casting about for a new project when at laser meetings AT&T people presented talks about optical communications.

- Optics had the bandwidth but they did not have a reliable low loss carrier.
- Corning took notice.

**And so it came to pass that AT&T had a group working on making better diode lasers and Corning, a glass company, set to work on making low loss fibers.**

- They did not plan this - it just happened that way.

In 1970 Corning was able to report a low loss fiber with only 17 db/km loss and so one part of the optical communications problem was in hand.



## The million hour diode laser

In 1977, **“being very careful and very clean”** AT&T Bell labs reported diode lasers with expected lifetimes of 1 million hours.

With the improved Corning fibers, communications over optical fibers was feasible.

In 1980 the winter Olympics was broadcast over fiber optics links. Just 18 years from the first diode laser to the first optical communications system.

**It was a MIRACLE!!!**

Today there are nearly  **$2 \times 10^9$  km** of optical fiber in the telecommunications system with millions of diode lasers as sources and amplifier pumps.

Today diode lasers are made by the multi-millions per year and are –

- in communications, supermarket scanners, laser printers, cd/dvd player/recorders, auto head lights, laser pointers, high power configurations for cutting and welding and solid state and fiber laser pumping, projection displays and ????.



**B. C. DeLoach, R. W. Dixon and  
R. L. Hartman received the IEEE  
Gold Medal for Engineering  
Excellence  
For the Million Hour Laser**

## Speculation

Speculation is very risky business but I will try just don't hold me responsible:

Lasers will make possible:

1. Spectacular movie theaters but all too soon these will be adapted to home theaters.
2. Greatly improved surgical precision perhaps using pulsed UV laser light.
3. Exploration of extremely fast processes – the shortest pulsed laser is at CREOL and is ~65 atto-sec.
4. Studies of ultra-high field physics – the ELI will achieve 200 peta W and open up new physics.
5. The US National Ignition Facility (NIF) will achieve fusion threshold and find out how to optimize inertial confinement fusion.

Plans for fusion power plants will be drawn up and then people will complain about tritium.

There will be enough other energy sources for enough time at much lower cost that this will not be built.

6. Manufacturing technologies based on lasers that sustain Moore's law for another decade or two.



## Far out speculation

Laser spacecraft propulsion.

Laser selective chemistry and biology.

X-ray lasers will find application in electronics.

- Will sustain Moore's law for several more decades.

Laser driven high energy physics – particle accelerators.

Space lasers for line of sight communications will become much more common.

- This will provide the bandwidth needed as the instrument packages become more capable.

Applications will be found for attosecond lasers.



## Thank you

Any additional reminiscences would be appreciated.

Any corrections too, but be nice about it.

Any additional speculations would be appreciated.

In 2016 OSA will publish a book commemorating its first 100 years. The Editor-in-Chief is **Paul Kelley** and the Associate Editors are **Carlos Stroud, Jeff Hecht, Michael Bass and Govind Agrawal**. I owe my colleagues in this effort thanks for involving me in this project as it made me more aware of the history of Optics and Lasers and the impacts they have made on how we live our lives.