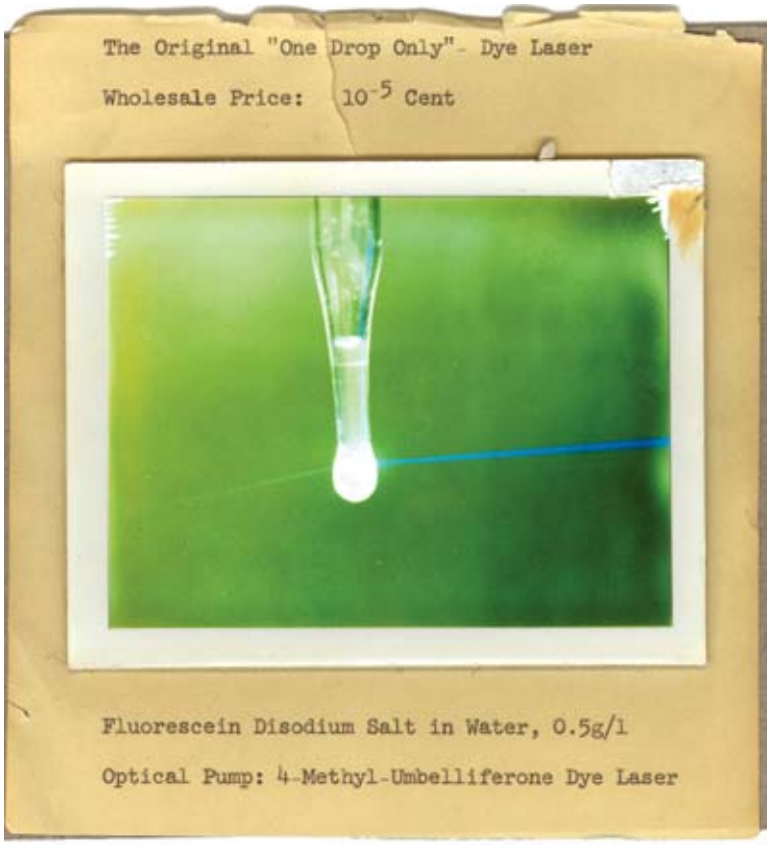


"One-Drop-Only" dye laser, a precursor of the edible laser. This picture was posted on a laboratory door at Stanford in 1970.

Edible Lasers and Other Delights of the 1970s

Theodor W. Hänsch

In 1970, Arthur Schawlow and Theodor Hänsch invented the world's first edible laser. Here, Hänsch tells the story of how, as a young researcher in Schawlow's lab, he paired his own ingenuity with Schawlow's contagious sense of humor to accomplish the feat, one of many notable achievements in the distinguished careers of two pioneers of laser research and development.

In early 1971, a short note on the laser action of dyes in gelatin[1] was posted on a number of university and corporate bulletin boards. Highlighted in the body of the note were the words, " … this may well be the first edible laser material." Although to some readers it all may have seemed little more than a frivolous joke, I felt rather proud of my first joint publication with Arthur L. Schawlow of Stanford University, co-inventor of the laser, whose laboratory I had joined as a postdoctoral student and NATO fellow in April 1970. In hindsight, this short paper marked the start of the most exciting period of my 40 years of research in atomic, molecular and optical science. Soon after experimenting with edible laser materials, we learned how to make widely tunable dye lasers highly monochromatic.[2] Spectroscopic techniques, such as Doppler-free saturation spectroscopy, polarization spectroscopy, two-photon spectroscopy and ultrasensitive fluorescence spectroscopy quickly became powerful tools with widespread applications. New ideas, such as cooling of gases by laser radiation pressure, emerged only a few years later.[3]

I had first met Art Schawlow at a summer school in Scotland in 1969, and I was immediately captivated by his warmth and playfulness, his contagious sense of humor and his keen mind. In those days, it was mandatory for a young German physicist to spend one or two years as a postdoc in the United States. I had long felt that it would be best to go to some laboratory on the West Coast, so that I could interrupt my flight and visit some laboratories in the east and in Boulder, Colo., without paying extra air fare. Fortunately, Art agreed to take me on as a postdoc and NATO fellow.

On my way to California, I stopped on the East Coast. At Bell Laboratories in Holmdel, N.J., I had the opportunity to visit Charles V. Shank and Herwig Kogelnik, who were experimenting with a small tunable dye laser pumped with a nitrogen laser made by AVCO.[4] The pump laser emitted superradiant ultraviolet flashes of about 10 ns duration and 1 mJ energy at repetition rates up to 100 Hz. At such high pulse rates, the bright dye laser beam looked almost continuous to the eye. This was a far cry from the few pulses per minute which I had obtained playing with a simple home-built flashlamp-pumped dye laser while I was a graduate student with Peter Toschek and Christoph Schmelzer at the University of Heidelberg, following the discovery of laser action in organic dye solutions by Fritz Schäfer and Peter Sorokin in 1966.

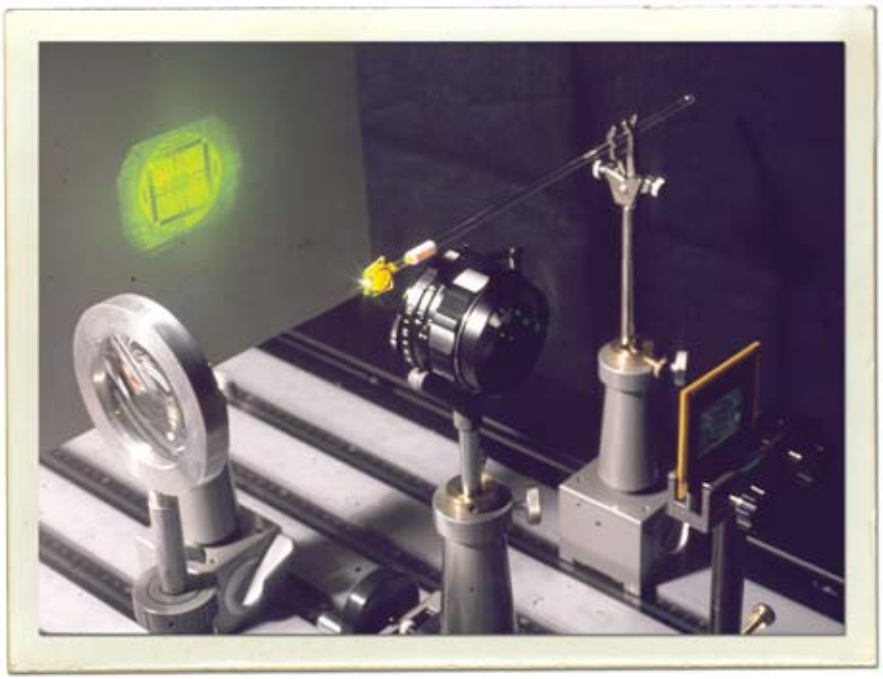
After arriving at Stanford, I told Art Schawlow about the interesting experiments at Bell Labs and proposed that I would try and make a nitrogen-pumped dye laser so highly monochromatic that it could be used for Doppler-free saturation spectroscopy of atomic gases. At Heidelberg, I had begun to explore such nonlinear laser spectroscopy, which was then still limited to the study of gas laser transitions or molecular lines in accidental coincidence. When Art asked how I would go about it, I replied that I would try prisms, holographic diffraction gratings, Lyot filters, etalons or whatever else would be necessary to restrict laser action to a single longitudinal mode.

Art and I had already discovered that we shared a passion for clever gadgets. He was sufficiently intrigued by my proposal to let me purchase an AVCO nitrogen laser using funds from a post-Sputnik-era Army contract. The nitrogen laser, which was delivered in July 1970, immediately

proved an irresistible toy. Many different laser dyes could be efficiently pumped simply by focusing the rectangular ultraviolet beam with a cylindrical lens to a line inside a glass cell or near the surface of the liquid in a beaker. The dye laser gain was so large that, even without a laser resonator, a collimated beam of amplified spontaneous emission appeared. With a diffraction grating at one end of a simple cavity, the output color could be changed by turning a knob.

Playing around in the lab one evening, I focused the blue output beam of a simple dye laser into a drop of sodium fluorecein solution which was dangling from a glass pipette. I felt thrilled when this drop became a dye laser of its own, emitting an intense beam of green light. A cavity had obviously been formed by the reflecting surfaces of the drop. I could not resist taking a picture of this "one-drop-only laser" with a Polaroid camera and posting it at the laboratory door. When Art discovered the picture he studied it for a surprisingly long period, probably because he had spent countless hours explaining to patent lawyers at Bell Labs just what the essential elements of a laser were. After examining the photo for some time, he postulated that "anything will lase if you hit it hard enough!"

To prove his point, he suggested we try to obtain laser action from one of the colorful gelatin desserts popular with children. The next morning he arrived with a packet of 12 different flavors of Knox Jell-O. In our small dark room, we prepared two flavors according to the instructions by adding 16 ounces of hot water to the contents of one bag. We poured the liquid into clear plastic cups, where a colorful gel of normal food consistency formed after several hours. We then took these cups with their wobbly content to the nitrogen laser and focused the pump light from the top to a narrow line. Although we could see strong fluorescence, we did not observe any laser action. In resignation, Art took the obstinate experiment to his office and savored it as a snack. This ritual was repeated every morning until we had tried all 12 flavors without success. Not one to give up, Art pointed out that sodium fluorescein is almost non-toxic. So we mixed up some clear gelatin with a small amount of this dye, and we soon had a potent new laser material, although Art no longer insisted on eating it. The gelatin laser medium was rather soft for optical work, but could be cut with a knife into laser rods or other shapes. Later we explored the behavior of other laser dyes in gelatin. For rhodamine dyes we found a significant improvement in performance when we added some kitchen detergent (Pink Lotion Trend) to the mixture to prevent the dimerization of the dye molecules, even though the edibility of the laser medium was thus further compromised. Finally, we also observed dye laser action with some of the Kodak Wratten gelatin color filters commonly used in many optical laboratories.



Dye laser image amplifier (Ref. 6). A slide with a test pattern is illuminated from the right with light from a weakly pumped dye cell. A camera lens projects an image on a screen. The brightness of the image is boosted up to 1,000 times by means of a short amplifying dye cell.

Inspired by this work, Kogelnik and Shank at Bell Labs soon realized the first distributed feedback laser with laser dyes in a holographic grating structure of dichromated gelatin,[5] and we felt that our snack experiment at Stanford had actually led to some useful new technology. Distributed feedback has since gained much importance with its application to semiconductor lasers.

Another by-product of the playful time in the lab was an intriguing dye laser image amplifier.[6] With Frank Varsaniy, a guest researcher in Art's group, we illuminated photographic slides with fluorescence from a weakly pumped dye cell and used a camera lens to project a dim image onto a screen. A short amplifier dye cell was then inserted into the light path after the lens where the rays converged near an image of the point-like light source. When pumped by the nitrogen laser, this dye laser amplifier could easily boost the intensity of the projected image by a spectacular factor of 1,000. It was unfortunate that for the most interesting case —very low light levels—the unavoidable quantum noise of such a laser amplifier imposed serious limitations.

Despite such distractions, I began to focus my efforts increasingly on the original goal of making a widely tunable dye laser highly monochromatic. After some initial encouraging results with a homemade holographic diffraction grating and a Lyot filter as tuning elements, I submitted an abstract with some optimistic claims to the Winter Meeting of the American Physical Society that was to be held at Stanford in December 1970.[7] But as the time of the meeting approached, I felt an increasing sense of panic, because

Arthur L. Schawlow, the author (*left*) and William R. Hewlett (*right*), with their newly awarded diplomas as California Scientists and California Industrialists of the Year 1973. Hewlett's partner, David Packard, was in Washington, D.C., at the time. [Palo Alto Times, May 11, 1973.]

none of the approaches I had tried could tame the laser spectrum reliably. Like other experimenters before me, I was working with a rather small beam diameter inside the dye laser cavity. Suddenly, I realized that the spectral resolving power had to be limited as long as only a small number of grating lines were illuminated. I happened to be carrying a small Zeiss monocular telescope in my pocket, which I often used to read the small print of slides or transparencies from the back of a lecture room. Quickly I mounted this telescope as a beam expander inside the cavity to fill the grating area more efficiently, and instantly I observed a dramatic improvement in the laser line width. With a larger beam expanding telescope and an additional etalon inside the cavity, the spectral width of the pulsed dye laser could be reduced to an unprecedented 0.0004 nm [Ref. 2], and an additional external filter etalon soon permitted the first experiments on Doppler-free saturation spectroscopy of atomic resonance lines.[8]

When Art saw the first Doppler-free spectra of the sodium D lines which I had left on his desk after an exhilarating night, he suggested that we should do the same with the red Balmer-alpha line of atomic hydrogen. This line had been at the center of attention of atomic spectroscopists in the 1930s because of suspected discrepancies from the predictions of relativistic Dirac theory. With Issah S. Shahin, a graduate student from Jordan, we quickly set up an old-fashioned Wood-style hydrogen gas discharge tube. Soon we were able to resolve single fine structure components of the red Balmer line, which for the first time made it possible for us to observe the 2S Lamb shift directly in the optical spectrum.[9] A few years later, the first laser measurement of the Rydberg constant improved the accuracy of this important fundamental constant by an order of magnitude.[10]

When word about the new tunable laser spread, a stream of visitors began to file through our unpretentious little laboratory, and an article describing the dye laser[2] soon became a "citation classic." In 1973, for this work, Art and I were named California Scientists of the Year by the California Museum of Science and Industry in Los Angeles. At the same ceremony, William Hewlett and David Packard were named California Industrialists of the Year. On the heels of such recognition, it became easy for me to clinch tenure as an associate professor at Stanford. After a promotion to full professor in 1975, I continued to work close to Art at Stanford for another 11 years, before returning to my native Germany in 1986.

For me, the Balmer line experiment was the beginning of a long quest for ever higher resolution and accuracy in laser spectroscopy of the simple hydrogen atom which permits unique confrontations between experiment and theory. Recent measurements of the 1S-2S two-photon resonance reached an accuracy of 1.4 parts in 10^{14}, establishing new laboratory limits for possible slow variations of fundamental constants.[11] Substantial future improvements appear possible with the help of new optical atomic clocks that use a femtosecond laser frequency comb synthesizer as the clockwork. Such comb synthesizers have revolutionized optical frequency metrology over the past five years,[12] but the roots of this technique can also be traced to the exhilarating 1970s at Stanford.[13]

Since the frivolous edible laser experiments at Stanford, I refuse to feel guilty about simply enjoying some playtime in the lab. At the University of Munich, I have even set up my own small toy laboratory, which has done much over the years to help me satisfy my curiosity, invent useful new tricks and preserve the immense sense of joy I experience through my involvement in the world of optical science.

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