⟨S|P|S⟩ swiss physical society

Nr. 61
Juni 2020

SPG MITTEILUNGEN
COMMUNICATIONS DE LA SSP

AUSZUG - EXTRAIT

Milestones in Physics (19)

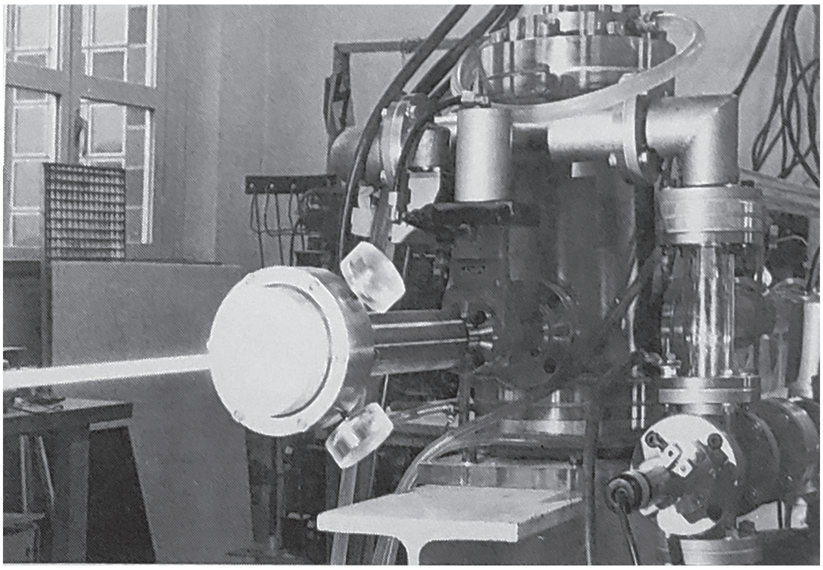
Laser Research in Bern

René Salathé, EPFL

International
Day of Light
16 May

IDL2020: Early Laser Research in Bern, Switzerland

In the years immediately after the first laser demonstration in 1960 in USA a lively research activity started in Switzerland and especially at the University of Bern. New laser concepts and metrology methods as well as medical and industrial applications were developed. The IDL2020 call to celebrate the 60th laser anniversary prompted us to collect, review and summarize the pioneering achievements of those days.



150 Watt Argon-Ion Laser Operation in Bern. The full story on p. 22. Reprinted from Laser Focus August 1970, courtesy of Endeavor Business Media, LLC.

Milestones in Physics (19)

Laser Research in Bern

René Salathé, EPFL

Introduction

The first report on laser emission in ruby by Maiman in 1960 [1] encouraged many laboratories around the world to start research on this entirely new light source. In Switzerland, first activities had been reported in 1964 by Hugentobler [2] on the application of a pulsed ruby laser in a bubble chamber and by Huber [3] on a new laser transition in NO. The University of Bern was able to establish in short time a prominent research group covering the most important topics in the new field. The group became the most important research center in this field in Switzerland at that time with international reputation. In this introduction we describe the background of this evolution and in the subsequent sections we recount the major events and achievements in the different fields of activities from the beginning until early 1980ies.

The University inaugurated in 1962 a new building adjacent to the main edifice above the main railway station, the "Institut für exakte Wissenschaften", after a long and painful planning and construction period. The new building hosted the mathematics, physics, and astronomy institutes. In advance to this event, the head of the Institute of Experimental Physics at that time, Fritz Houtermans, together with Hans König, Director of the "Eidgenösische Amt für Mass und Gewicht" and part time professor in the Experimental Physics wrote a letter to the Bernese government suggesting to create an Institute of Applied Physics in analogy to a similar institute at the University of Basel. The new institute should cover the more industry related research with respect to activity of the Institute of Experimental Physics. The Bernese government accepted these plans in 1961. Klaus Peter (KP-) Meyer, a physicist from the group in Basel, moved in 1961 to Bern and became the first director of this institute. He and his wife who worked for a long time as secretary of the institute are shown in Fig. 1.

Fig. 1: Prof. K. P. Meyer and his wife at the15th IAP anniversary in 1976 [4]

K. P. Meyer had been active in measuring the strengths of radioactive sources in absolute units using a coincidence method. In addition to his own activity, he looked out for new research topics. He couldn't find sponsors for his first idea to start research in superconductors. But the first demonstrations of generating laser radiation in crystals, gases, and semiconductors and the many potential applications - at that time speculative - of this new light sources convinced industry and government that research in this field could become important for Switzerland. K. P. Meyer was able to build up a research group consisting of two physicists (Hans-Peter Brändli, René Dändliker) and an electrical engineer (Jörg Hatz), all graduated with their diploma from ETH Zürich and financed on external funds. He convinced the general directorate of the Swiss PTT and 16 industrial companies [1] to sponsor an international conference in order to assess the status in laser research and applications. The newly formed laser group was involved in the preparation and organization of the conference that was announced in spring 1964 and took place in Bern in October 1964. After a conference focusing on laser physics organized in 1963 in Paris [5], the meeting in Bern was the second international event organized in Europe. It covered all scientific laser topics: General laser physics, nonlinear optics and Raman scattering, solid state lasers, gas lasers, injection lasers, chemical lasers. In addition, it included presentation on all emerging laser applications known at that time: be it in the fields of physics, in testing and measurements, in material processing, in optical communication, in medicine, or in biology [2]. Therefore, the most important academic, industrial, and governmental research laboratories from all around the world sent collaborators to present their latest work and more than 250 participants from 22 countries participated.

The proceedings of the conference were published 5 months later in a special issue of the "Zeitschrift für angewandte Physik und Mathematik" [6]. The new laser group was completed the same year with other physicists from ETHZ, Heinz P. Weber and Christian Deutsch, as well as Max Keller, Ernst Mathieu, and Alfred Roulier, physics students from Bern. The edition of the conference proceedings and the discussion of the results presented at the conference helped the members of the laser group to consolidate their know-how and to strengthen (or start) activities in the fields of gas lasers, solid-state lasers, non-linear optics, diode lasers, laser ranging, and drilling holes in ruby, topics that will be discussed in the following sections.

Some of the conference sponsors together with the Swiss Armaments Services Group were convinced of the need to have a permanent group of specialists available informed about the latest laser developments. K. P. Meyer formed a core group that financially supported the laser group. The latter delivered quid pro quo regularly reports to them and – on request – analyzed particular developments. This additional support allowed hiring more PhD students so that veritable research groups could be formed to cover the most important fields.

1 Albiswerk AG, Zürich; Balzers AG, Balzers; Brown-Boveri AG, Baden; Buhrle & Co., Zürich; Ciba AG, Basel; Djievahlrdjian SA, Monthey; Geigy AG, Basel; Generaldirektion der PTT, Bern; Hasler AG, Bern; Hoffmann-La Roche AG, Basel; IBM Forschungslaboratorium, Zürich; Impulsphysik AG, Zürich; Kontron AG, Zürich; Paillard SA, Yverdon; Philips AG, Zürich; Sandoz AG, Basel; Siemens AG, Zürich; Turlabor AG, Zumikon

2 Comprehensive conferences covering all laser topics didn't yet exist, e.g. the very first CLEO conference, then called CLEA Conference on Laser Engineering and Applications), took place in 1969.

When the first research generation finished their PhD works and gradually left the Institute for working in industrial laboratories, K. P. Meyer looked out for experienced laser researchers in the field for guiding and managing the increasing number of diploma and doctoral students. He hired Gerd Herziger and then Horst Weber, both students of Hans Boersch, the former director of the "1. Physikalische Institut" at the Technical University of Berlin. They graduated there in 1965 and were engaged in Bern 1969 as lecturers (Privatdozent). Gerd Herziger supervised the gas laser and laser processing activities, in particular the drilling of holes in watch stones. He became associate professor in 1970, full professor in 1974 but left the Institute in 1975 with an appointment as full professor at the Technical University of Darmstadt [3]. Horst Weber supervised the non-linear optics-, the solid state-, dye- and diode-laser activities and was promoted associate professor in 1972. He left the Institute also in 1975 with an appointment of full professor at the University of Kaiserslautern [4].

Heinz P. Weber, another physicist from ETHZ hired shortly after the laser conference by K. P. Meyer, finished his PhD at the IAP in 1968. When he presented his work on the measurement of picosecond pulses in the US (c.f. below), he received immediately an offer to work as staff member with the Bell Telephone Laboratory in Holmdel. He worked there until 1975, when K. P. Meyer invited him to come back to head the orphaned laser group. He was appointed associate professor in 1975, full professor in 1983, and he successfully increased the international reputation of the laser group once more [5].

Solid State Lasers

Ruby Lasers

Pulsed ruby lasers were one of the most advanced systems with respect to applications at the time of the laser conference in Bern. In the early 1960ties, optics was a stepchild among the fields of physics; some universities had even removed this topic from their physics curriculum. Optical rail systems with triangular cross-section developed in 1912/1913 by Carl Zeiss in Jena ("Zeissschiene") were used for experiments. Optical components were mounted on stands that were shifted along the length of the rail and bolted down at the desired position. The possibilities of adjusting the lateral position and angular direction of the component were very limited and the adjustment precision was unsatisfactory for laser experiments. New optical mounts had to be designed and fabricated in the workshop of the institute. The first free running ruby laser was constructed at the IAP by René Dändliker in 1964 (Fig. 2). This laser became then the workhorse of Heinz P. Weber in 1964 for the experiments in non-linear optics.

3 Gerd Herziger moved in 1985 to the Technical University of Aachen, where he founded the Fraunhofer Institute for Laser Technology (ILT) in the same year. This institute focused on industrial research grew rapidly under Herziger's leadership to become the largest European laser research center.

4 Horst Weber returned to the Technical University of Berlin in 1987 and worked as full professor for Applied Laser Physics and Head of the Institute for Solid State Lasers until his retirement in 2003.

5 Heinz P. Weber stayed in Bern and co-directed the Institute of Applied Physics until his retirement in 2004.

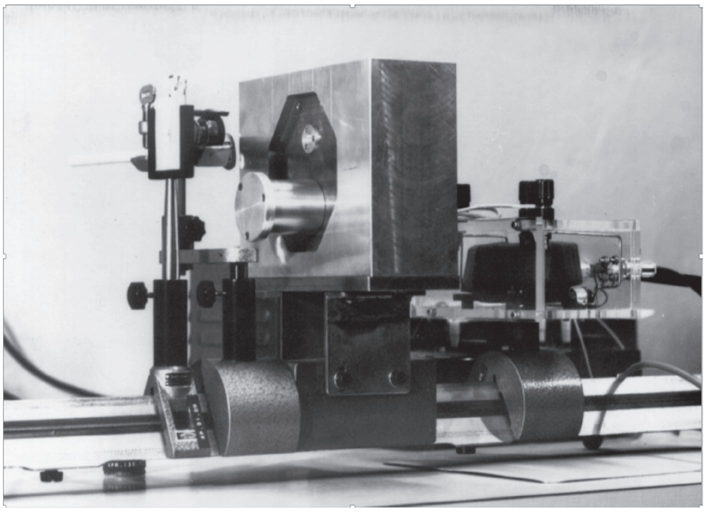


Fig. 2: IAP Ruby laser in 1964 [4]

The ruby crystals were procured from Djeva SA in Monthey, Switzerland. This company also delivered the first ruby laser crystals to the United States in 1960. Their crystals were fabricated by flame fusion ("Verneuil" process) and had not yet the optical quality of today's crystals drawn with the Czochralski process. The crystals were excited by a helical flash lamp placed inside a cylindric metal reflector (Fig. 3).

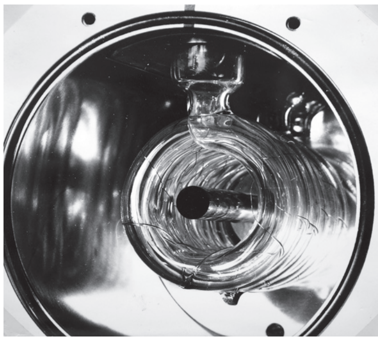


Fig. 3: Ruby laser cavity [7]

Ruby lasers emit in the red (694 nm). The active ion (Cr^{3+}) has a very long fluorescence lifetime (3 milliseconds) that allows for high energy pumping and for generating light pulses useful for demonstrating the material processing potential of such lasers, by e.g., drilling holes into razor blades (Fig. 4) and coins.

Fig. 4: Impact of ruby laser pulse on razor blade [7]

Using a variable attenuator within the laser cavity such as, e.g. a dye cell or a rotating prism, the energy stocked in the crystal can be released in one single light pulse. The technique, called Q-switching, allows generating light pulses with Megawatt peak powers (at the time called "giant" light pulses). It was investigated in parallel to the explorations on the spatial and temporal emissions of "free running"

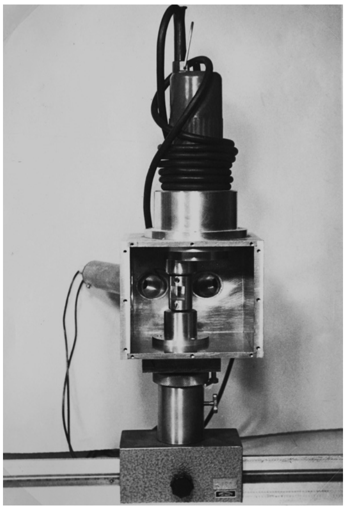


Fig. 5: Rotating prism [7]

ruby laser. An idea of the experimental technique back in 1964 is illustrated in the following figures. Fig. 5 shows a rotating prism mounted on a Zeiss rail. Fig. 6 illustrates the experimental set-up for a Q-witched laser with the home built high voltage electric supply and condenser bank on the left and the laser set-up on the right.

Q-switched lasers allowed generating air breakdowns (Fig. 7), but they also created problems when working with such intensities: The layers of dielectric mirrors had too much residual absorption and could not withstand high light intensities (Fig. 8). This problem was investigated in a collaboration with Balzers AG in Lichtenstein and in the framework of a diploma work at the IAP that allowed to fabricate dielectric mirrors with very high reflectivity and damage threshold [8].

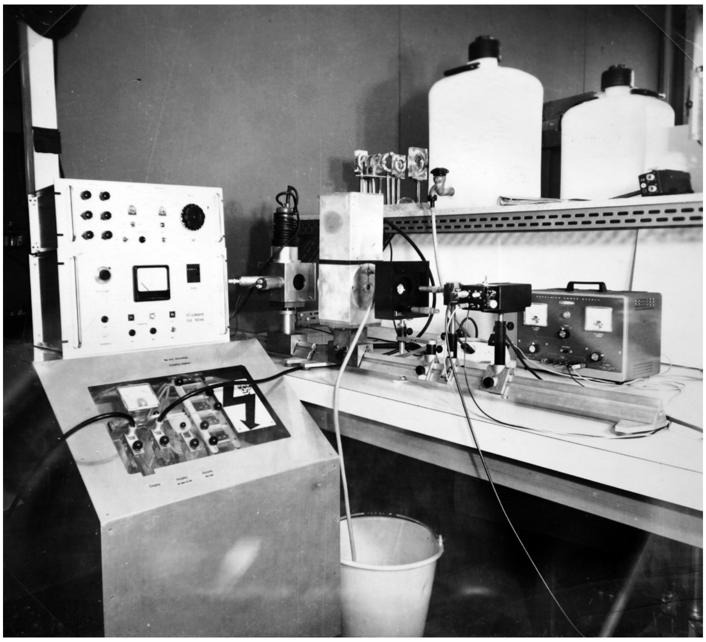
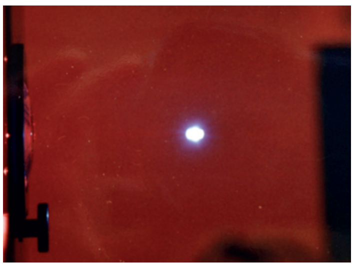


Fig. 6: Q-switched Ruby laser [7]



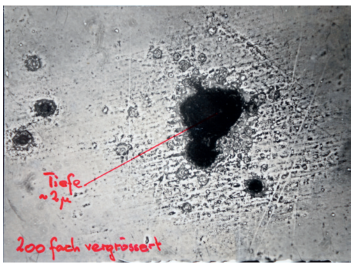


Fig. 7: Air breakdown [7]; Fig. 8: Damaged dielectric mirror [7]

ND:YAG Lasers

Ruby lasers were fine for demonstrations and Q-switching at low repetition rates. But, the underlying three-level energy scheme required high pump intensities for reaching the laser threshold. Continuous working (cw-) operation or high-average pulsed laser operation necessary for industrial laser application could not be achieved. Nd:YAG lasers (Neodymium-doped Yttrium-Aluminium-Granat crystal) don't have these problems. This type of laser had been developed in 1964 at the Bell Laboratories by LeGrand Van Uitert and Joseph E. Geusic [9]. The laser active ion, Nd^{3+}, absorbs light in the near infrared, at 730 - 760 nm and 790 - 820 nm respectively. The laser emission line is at 1060 nm. Nd:YAG has a 4-level energy scheme, i.e. the lower energy level of the laser transition is situated above the ground level so that the threshold for laser emission is attaint much easier. The laser was also pumped by flashlamps in the same configuration as for ruby lasers. The solid-state laser team procured Nd:YAG crystals and glass rods right away when the first publications appeared in 1964 and developed this type of laser further for research in mode-locking experiments, in non-linear optics, generation of plasma, and for industrial applications, particularly for drilling holes into watch stones (cf. below).

Nonlinear Optics

The high intensities that could be achieved with Nd:YAG lasers were used already in 1966 by Heinz P. Weber and Ernst Mathieu for frequency doubling (conversion to green light) in crystals whose structure does not show inversion symmetry, e.g. Potassium Dihydrogen Phosphate (KDP) and Lithiumniobate ($LiNbO_3$) [10]. Theoretical studies and investigations on the symmetry, on the optical dispersion, and on the birefringence had to be considered for achieving synchronization of the various participating optical beams [10, 11]. This research lead Heinz P. Weber subsequently to the development of a novel correlation technique for measuring the pulse duration of ultra-short pulses [12-14]. Such pulses had been generated and reported by A. J. DeMaria in 1967 [15]. But their duration could not be measured since no photo-detection system existed at that time with a time resolution below a nanosecond. The new technique was then applied to study the asymmetry and the behavior of ultrashort pulses. Fig. 9 shows the optical set-up used in 1968 in the framework of the diploma work of Bruno Hausherr [16]. Heinz P. Weber's correlation method was quickly adopted by the laser community and became for a long time a standard technique for characterizing ultrashort laser pulses. The method is presently still used routinely to study f-sec pulses.

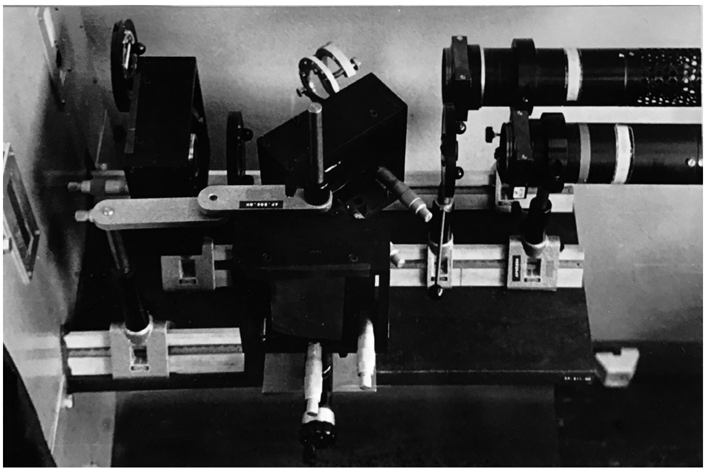


Fig. 9: Experimental arrangement for intensity correlation measurements [16]

Laser Plasma

The generation of plasma with high-power lasers played a crucial role in the interaction of radiation with metals, in particular for drilling holes. This was investigated at the IAP in the thesis work of Martin von Allmen [17, 18]. After his thesis Martin stayed at the IAP and headed a research group investigating in detail the new possibilities that arose by the rapid heating and cooling down in the interaction of laser pulses at the surface of solids, in particular silicium (Si). With his collaborators Willy Lüthy, Klaus Affolter, and Markus Wittmer, he investigated, e.g., the laser assisted doping of Si [19], the epitaxial growth of deposited Si-layers on Si [20], or the laser induced reaction of magnesium on Si [21]. Many of the results he elaborated during his work at the IAP had been published later in a book [22].

The possibility of generating shock waves in hot plasma with mode-locked lasers let people dream that this technology could be scaled up to such an extent that one day nuclear fusion could be initiated by symmetrically irradiating, heating up, and compressing pellets of the size of a pinhead containing a mixture of deuterium and tritium. According to work performed in the U.S. at the Lawrence Livermore National Laboratory (LLNL) and published by Nuckolls et al. [23], pulses with energy above one kilojoule at the target would be needed for ignition, and hundreds of kilojoules for sufficiently high energy gain. For comparison, short-pulse (picosecond) energies of at most a few joules were available in the early seventies [24]. So many research groups started work in scaling up the pulse energy of mode-locked lasers. When Horst Weber arrived in Bern in 1972, he hired a PostDoc collaborator from Euratom (European Space Research Institute, ESRIN) in Frascati/Italy, Wolfgang Seka, with experience in laser generation of plasma and plasma diagnostics. Because of the shutdown of the laser-plasma activity in Frascati, Wolf Seka arrived in Bern with a truck filled with Nd:YAG/glass amplifiers, power supplies, control electronics, fast oscilloscopes, and other state-of-the-art laser equipment. Together with PhD students, a research group was formed at the IAP, which soon was able to contribute in the fields of pulse amplification and plasma generation and -spectroscopy. A modest Nd:YAG/glass laser source delivering pulses of 1 J in 30 ps, mostly based on the "ESRIN components", was developed and used for the experiments (Figs. 10, 11) [25-28].

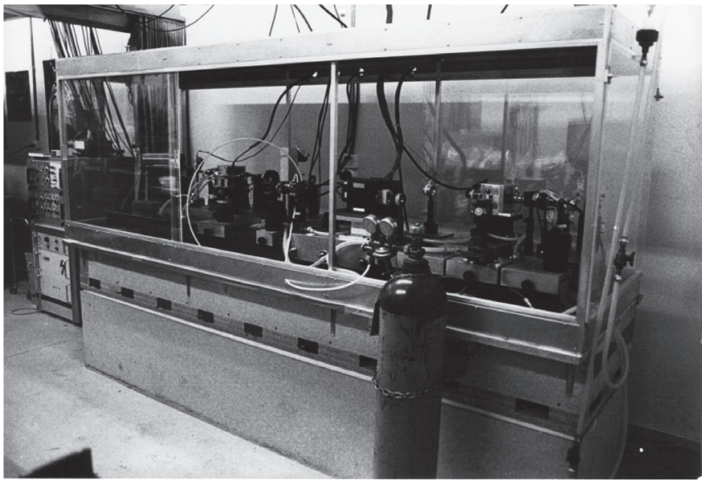


Fig. 10: "IAP Plasma" Laser ca. 1976. Nd:YAG oscillator and discrimination amplifier table. The nitrogen bottle in front of the table served to pressurize a laser-triggered spark gap used to select a single pulse from the train of mode-locked pulses [29].

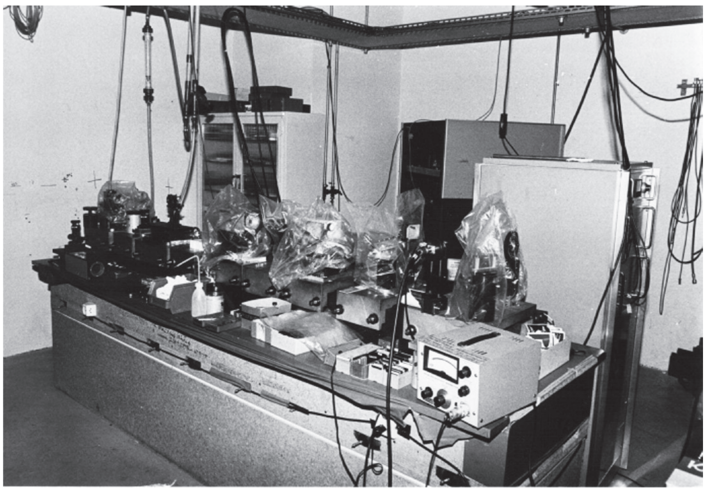


Fig. 11: Nd:glass amplifier table. Two 20 mm diameter rods pumped by helical flashlamps (KORAD Laser Systems) boosted the pulse energy to ~1 J [29].

HE-NE

In 1961 the first laser emission at an infrared wavelength of 1.15 μm was demonstrated in a He-Ne gas discharge by Javan et al. [30]. Emission in the visible at 0.63 μm by White et al. [31] and a systematic study on the optimal discharge conditions at both wavelength by Boersch et al. [32] were reported shortly afterwards. At the IAP Hans Peter Brändli, René Dändliker and new diploma students, Peter Blaser and Theo Tschudi started working in this field. Discharge tubes were prepared at the IAP with the help of the glassblower and vacuum equipment at the Institute for Experimental Physics and the first home built He-Ne lasers were operated in 1964 (Fig. 12).

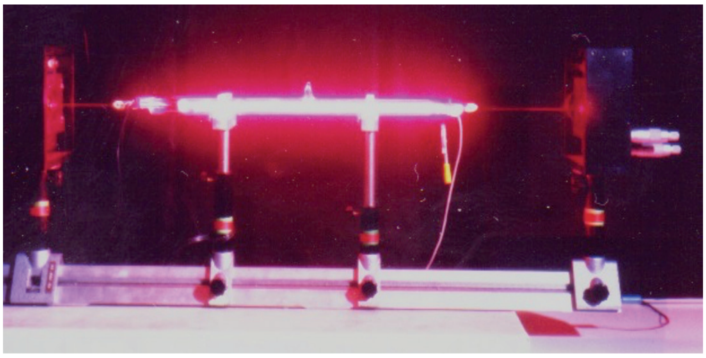


Fig. 12: He-Ne laser in 1964 [4]

New ideas for absolute frequency stabilization of He-Ne-lasers [33-35], for measuring small losses [36], on the polarization of gas lasers [37-39], and on coupled resonators were successively published [40]. When reliable He-Ne lasers became commercially available around 1969, the IAP group focused on developing measurement techniques and applications in interferometry [41-43] and holographic techniques [44]. With the arrival of Gerd Herziger in 1969 the activities included also more application oriented research such as, e.g. light scattering and particle size measurements [45-47], optical correlation techniques and quality control [48-53], Moiré techniques [54, 55], and spatial light modulation [56].

Ion Lasers

The transition (decay) from the lower laser level in a He-Ne laser is not fast enough and has to be accelerated by collisions with the tube walls. Because the number of collisions with the tube walls increase as the tube becomes narrow, the laser gain is inversely proportional to the tube radius. Laser gain, tube radius and tube length being limited, the output power of He-Ne laser is limited typically below 100 mW and cannot be scaled up. Gerd Herziger and Horst Weber started to work on Argon ion laser in 1967 while they were still with the Boersch group at Berlin [57]. Ar^{2+} is the laser active ion in the discharge and its lower laser level decays by radiation. However, the excitation efficiency in this system is very poor, typically 6.7% for the quantum efficiency and 0.1% for the wall plug efficiency. Energy efficiency or saving was not yet an issue at these times and this system was an ideal candidate for scaling up the output power of visible lasers. But the poor thermal conductivity of quartz glass limited the evacuation of the enormous heat load from the plasma through the tube walls. The group developed tubes composed of anodized aluminum rings (Fig. 13) screwed together [58].

Fig. 13: Ar-ion laser discharge tube segment with 32 mm inner diameter [59].

The good thermal conductivity of aluminum evacuated the heat, the oxide layer between the rings prevented from short circuiting anode and cathode. When Gerd Herziger moved to Bern, he had soon Wolfgang Seelig and Karlheinz Banse, the key Ar-laser people, follow him. Together with a technician, Jürg Steinger, and later a diploma/PhD student, Hansruedi Lüthi, the team built the most powerful visible and UV laser at the time with an output power of 150 W at the 514 nm line (Fig. 14).

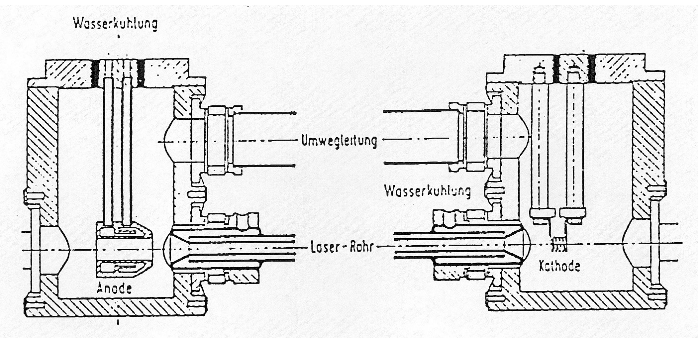


Fig. 14: Schema of the Ar-ion laser in Bern

The operation of this laser was quite impressive: The laser was mounted on a long granite table, with the electric supply consisting of transformer, rectifier, and solid cables, the howling of turbo vacuum pumps and the noise of the water pumps used for cooling the tube. Jealous colleagues jokingly claimed that in Bern the tram operation had to stop, when the laser was in operation.

The Ar-ion laser had a major problem: During starting-up, operation, and shutting down the laser tube was subjected to mechanical and thermal stress that lead to the formation of cracks in the oxide layers of the Al rings. The surrounding cooling water penetrated into these cracks, damaged the isolation between individual rings producing short circuits between anode and cathode. The damaged rings had to be found, the tube was unscrewed, the damaged rings replaced, and then the tube was reassembled. Maintenance time for the laser was orders of magnitude longer than the operating time and this was one of the main reasons, the laser tube could never be commercialized. However, the operation of this laser was spectacular for the public. Wolfgang Seelig used to light a cigarette for demonstrating the intensity of the parallel and unfocussed beam. But one day, in a public demonstration, his finger with wedding ring slid into the beam and a reflex hit the eye of a spectator. The ophthalmologist, Franz Fankhauser, was consulted. He found a small retinal coagulation outside of the field of vision, which fortunately had no consequences. The director of the institute, alerted about the security of his collaborators, asked Franz Fankhauser to check the retina of all collaborators when they started working in the laser group and when they left the institute. Fortunately, Fankhauser never found a damage, and the systematic controls were stopped about a decade later.

Dye Lasers

Dye lasers were discovered in 1966 by two groups, Sorokin and Lankard [60] at IBM research laboratories, and Schaefer et al. [61] in Göttingen. Here, fluorescent dyes are used as lasing medium, e.g. rhodamine 6G (emitting in the orange), fluorescein (green), coumarin (blue). They are usually dissolved in liquid solution (e.g. water, ethanol, ethylene glycol, or dimethylsulfoxide). They are excited by optical pumping with a flash lamp or another laser with optical conversion efficiency between 10% and 30%. The optical gain per unit length and the gain profile are much larger as compared to gas or solid-state lasers. Because of the high gain, pulsed dye lasers were easily set up: A glass cuvette with the solution, a discharge lamp for excitation and an alumina paper wrapped around the lamp and the cuvette. The reflection on two parallel walls of the cuvette was sufficiently high to achieve laser emission. A visible parallel light beam and interference pattern from the cuvette walls emerged perpendicular to the cuvette walls and convinced the audience that it was laser radiation. Contacts with the Schaefer laboratory facilitated knowhow transfer and from the late sixties on variation of this experiment had been one of the standard laser demonstrations in Bern.

In contrast to solid state laser materials dye molecules have very short fluorescence lifetimes (typically a few nanoseconds). This requires very powerful pump sources for excitation. In 1972 Peter Anliker and Michael Gassmann realized a flashlamp pumped rhodamine 6G dye laser with a maximum output energy of 12 J in a 5 μs pulse at 1 kJ electrical input energy [62].

Organic dye molecules have the tendency to become trapped in triplet states, in which they cannot participate in the lasing process. Moreover, during operation, laser dyes tend to be chemically degraded. These problems made it difficult to achieve continuous operation. In Bern, the high power Ar-ion laser was used to pump dye lasers [63]. Three PhD students, Michael Gassmann, Hansruedi Lüthy, and Peter Anliker, investigated dye lasers [64]. Anliker looked into the homogeneity of rhodamine 6G jets, an important parameter for achieving high power outputs. In collaboration with three colleagues from the Institute of Inorganic chemistry, Anliker et al. achieved with rhodamine 6G at the beginning of 1977 a conversion efficieny of 30% and a record cw output powers of 33 W [65]. After submission of the manuscript they achieved in March 1977 even 52 W of cw power in the red with an Ar-ion pumping power of 175 W !

CO_2 Lasers

The carbon dioxide (CO_2) laser emits infrared light at wavelength bands centered at 9.4 and 10.6 μm. It can be operated under cw- or pulsed condition and is characterized by quite high quantum efficiency (~30 %) and overall efficiencies (ratio of output power to pump power) of up to 20 %. In 1964 when the laser was first described in the scientific literature by Kumar Patel from Bell Laboratories [66], Robert A. Kaplan from the US company TRG in Melville N.Y. demonstrated already laser welding with a pulsed laser. The gas laser team at the IAP had acquired over the years a detailed know-how on the excitation of the gases by electric discharges at all pressure levels. Two PhD students, Michel Dufour and Hans Egger started to investigate CO_2-Lasers with transverse excitation, i.e. the gas discharge occurs perpendicular to the optical axes. These so called TEA-(Transversely Excited Atmospheric-) lasers can be operated in a pulsed mode at atmospheric pressure or above and are particularly simple to build: They consist of an isolating tube, e.g. plexiglass, filled with a mixture of N_2, He, and CO_2, sealed with two mirrors (one semi-transparent). Along the inner tube wall, an anode and cathode in form of metal strips, e.g. alumina, are placed on opposite sides. Alternatively, the cathode can also be formed by a series of evenly spaced nails that penetrate the tube wall opposite to the anode. The gas is excited by a discharge from a capacitor and the infrared beam emerges through the semi-transparent mirror. The discharge occurs in a myriad of filaments from the cathode to the anode. This results in a strongly non-uniform gain profile and a highly multimode laser emission. Two PhD students, Michel Dufour and Hans Egger started to investigate the homogeneity of various types of self-sustained TEA laser discharges in CO_2-N_2-He mixtures by analytical methods and experiments [67]. They added volatile organometallic gas molecules with a low ionization potential (ocenes) and used flash lamps to pre-ionize the whole volume immediately before the main gas discharge. This new technique allowed achieving a more uniform gas discharge and gain profile [68]. Emission under controlled transversal mode and uniform laser pulse conditions could be achieved. The technique worked in CO_2–N_2–He mixtures between 1 and 5 atm and offers a large scalability [69].

Diode Lasers

The first laser emissions from gallium arsenide (GaAs) p-n junctions were reported in 1962 by three groups in the USA [70-72]. The work in Bern started, when K. P. Meyer hired in 1964 the PhD student Jörg Hatz and shortly afterwards Christian Deutsch, Eugen Mohn, and later Ronald F. Broom. At that time GaAs was an exotic semiconductor material. Monocrystalline n-doped boules of ~1 inch diameter were grown by Czochralski and cut into 500 μm thick wafers. At that time the Batelle Institute in Geneva was active in this domain and the group in Bern could obtain wafers from them. A small fraction from a boule is shown in Fig. 15.

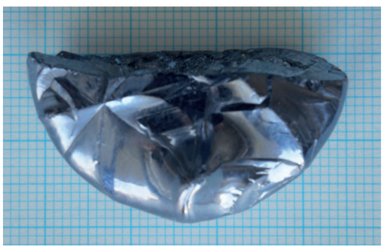


Fig. 15: lower part of GaAs ingot

Diodes were prepared by zinc diffusion at 850° in a hydrogen atmosphere, by grinding and polishing the wafer on one side to a thickness of 150 μm, applying gold contacts, sawing and cleaving the wafer into diodes of 400 μm length and 125 μm width, and mounting individual diodes on a modified TO-5 transistor head. The first diodes could only be operated at liquid helium (4°K) or liquid nitrogen temperature (77°K) because the laser threshold increased dramatically with temperature. The diodes were mounted at the bottom of a copper rod in a small vacuum chamber with two optical windows. The top of the rod was cooled in a Dewar bottle filled with liquid nitrogen. The arrow in Fig. 16 indicates the position of the diode.

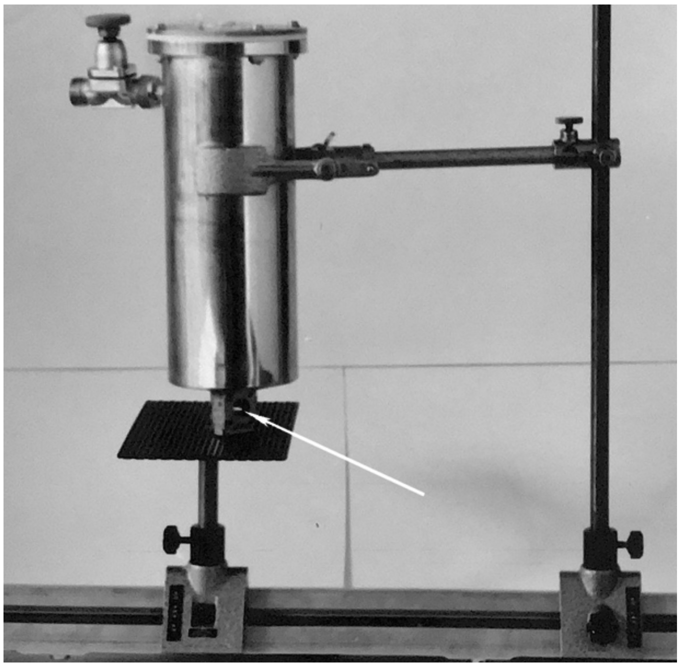


Fig. 16: Early experiments with Gallium Arsenide laser diodes [73]

Within 2 years the group managed organizing or buying and put into operation the necessary equipment for the semiconductor technology, for working at cryogenic temperatures and for optical diagnostics. First scientific results were reported in 1966/67 [74-77].

The first generation of PhD students was gradually replaced from 1967 on by a physicist from ETHZ (Christian Risch) and new diploma students (René Salathé, René Keller, Claude Voumard). From 1968 on the p-n diodes were prepared by liquid phase epitaxy, a method originally proposed by H. Nelson [78]. P-layers with higher doping concentrations and a steeper gradient at the p-n junction could be fabricated leading to lower threshold currents. A GaAs wafer was fixed at one end of a graphite boat, Ga with pieces of GaAs and Zn on the other end. The boat was loaded in a tube under oblique angle with the wafer at the upper position, heated up under hydrogen to 750°C. The liquid and saturated Ga solution was brought into contact with the wafer by tilting the oven and an epitaxial layer of some ten μm was grown on the wafer by slowly cooling down the melt. The equipment is shown in Fig. 17.

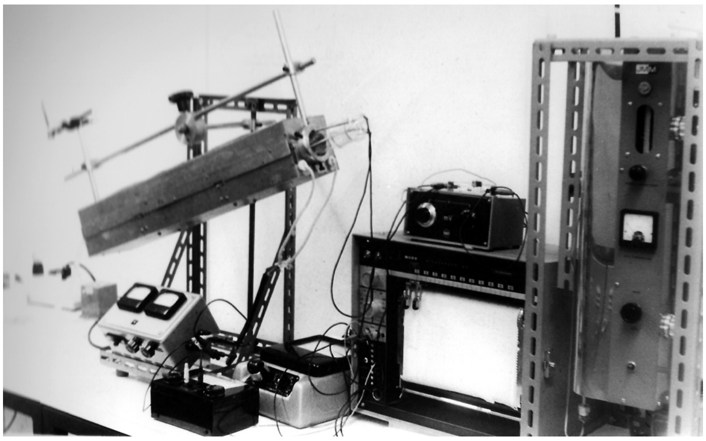


Fig. 17: Tilting oven (left) for GaAs liquid phase epitaxy with hydrogen purifier (right)

In the 1970ties the technique has been improved by inserting a glider with bins containing Ga-solutions in the graphite boat, that were in the cooling down phase successively moved over the GaAs substrate fixed at the bottom. This allowed to grow layers with different compositions of GaAlAs and doping material. This key technique, originally proposed by Zh. I. Alferov [79] and M. B. Panish [80], allowed to grow hetero-structures that confined carriers and photons to a thin layer at the p-n junction and reduced the laser threshold current to levels that made continuous operation at room temperature possible. The group, now under the direction of Horst Weber, was forced to reproduce this technology in order to have diode lasers available because they were not yet available commercially.

A technician, Jean-Marie Kuenzi, assisted the group in preparing and mounting individual diodes on specially designed copper mounts that allowed optical access on both mirror facets. René Keller was able to perform interferometric measurements on the deformation of the tiny diode mirrors during pulsed operation of the diodes at room temperature [41, 43]. René Salathé investigated the optical coupling of two laser diodes [81, 82]. Claude Voumard and Christian Risch looked into the properties of diode lasers coupled to external resonators [83-85].

After the first demonstration of continuous working diodes at room temperature based on double hetero-structure diodes [86, 87] many industrial research laboratories got involved with fabricating diode lasers. The group started a collaboration with the laboratories of Marcoussis near Paris in France, the research center of the "Compagnie générale d'électricité". In exchange to technological know-how transfer they received professionally fabricated laser diodes. The time-consuming production of own laser diodes was no longer necessary. In 1975/76, Franz-Karl Reinhart spent half a year of his sabbatical from Bell Telephone Laboratories as invited professor at the IAP. The collaboration with him and his collaborators in Murray Hill enabled the group to work with advanced material used for integrated optics. Yolande Rytz-Roidevaux, a PhD student from the Ecole Polytechnique in Lausanne, and two diploma students, Gerhard Badertscher and Heinz Gilgen, joined the group and the focus of research activity turned to laser processing of semiconductor laser material [88, 89].

Laser Applications

Ophthalmology

The ophthalmologist Franz Fankhauser was interested in performing systematic studies on retina coagulations with lasers. In search for a reliable industrial ruby laser he visited together with Alfred Roulier the Siemens laboratories in Munich, where they performed coagulation experiments on the retina of a rabbit. They returned to Switzerland not without some difficulties in bringing rabbit and laser through the customs. Franz Fankhauser, Alfred Roulier, and an optics expert from the Federal Office of Weights and Measures, W. Lotmar, conducted systematic studies from 1967 onwards on retina coagulation with patients at the ophthalmologic clinic of the University Hospital ("Inselspital") in Bern. The experimental studies were backed up by Alfred Roulier who calculated in the framework of his thesis the temperature increase in the eye produced by intense light [90]. The experiments represent the first medical applications of lasers in Switzerland and paved the way in establishing lasers mounted on slit lamps as efficient medical treatment for circumventing retinal detachment [91-94].

In 1968 Franz Fankhauser came up with the idea to clot blood vessels in the choroid (bloodshot eye) with the newly available argon laser light. A small fraction of the light was decoupled with a beam splitter and transferred to an ophthalmoscope that was mounted aside of the laser. The patient, a robust truck driver, was sedated with copious amounts of cognac before starting the laser machine. The attempt was successful but remained an episode. The more than bizarre scene was re-enacted after the operation with Alfred Roulier mimicking the ophthalmologist and the secretary of the institute as patient (Fig. 18). Jürg Steinger, the technician of the Argon laser group operated the laser.

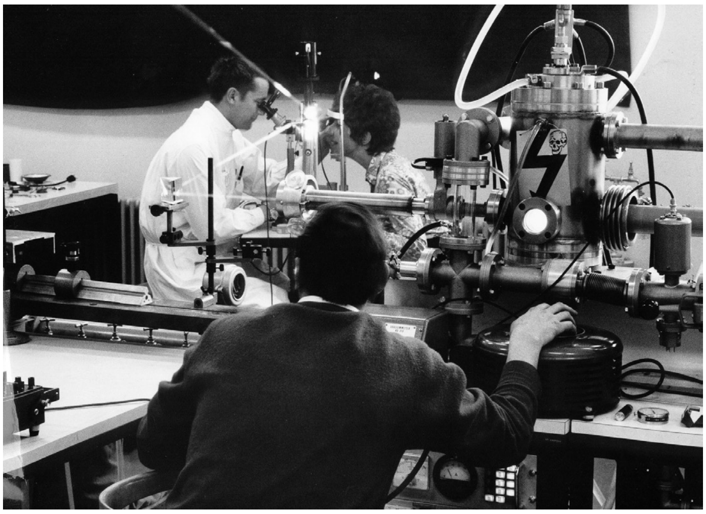


Fig. 18: Medical Application of Ar-ion laser [95]

Satellite Telemetry

A proposal to use Q-switched Ruby-lasers for satellite telemetry has been elaborated in 1967 by Max Keller [96]. He estimated to achieve an accuracy in distance measurements of 0.5 m for satellites equipped with reflectors for costs of about 300'000 CHF. A project proposal was submitted to the Swiss National Science Foundation in collaboration with the Astronomy Institute (Prof. M. Scheurer). The accepted project allowed to equip the 60-cm telescope at the Observatory of Zimmerwald with a Q-switched ruby laser system (Fig.

19). First measurement could be performed in spring 1971. An accuracy of 0.5 m was reported in 1972 for distances of 1000 - 3000 km [97].

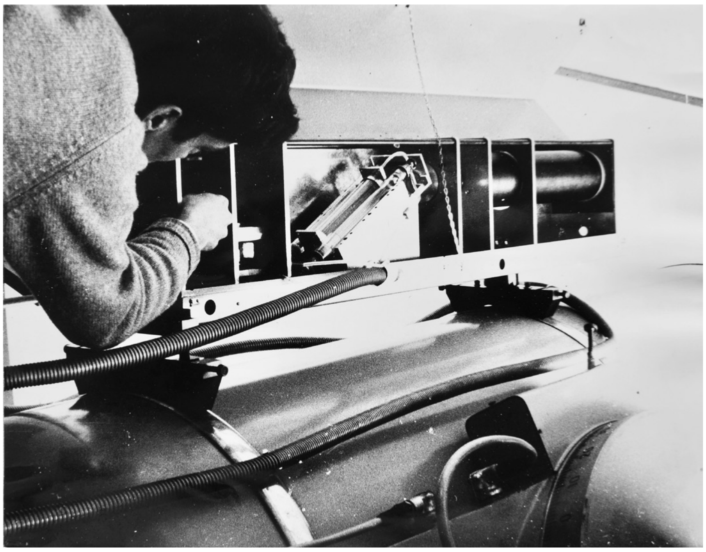


Fig. 19: Mounting of the ruby laser on the telescope in Zimmerwald [7]

Drilling Of Watch Stones

In the early 1960ties the Swiss Watch Industries produced 50 million ruby watch bearings per month (17 – 21 jewels per watch) and drilled for that 50 μm diam. cylindrical holes in ruby discs (1 mm diam. 0.3 mm thick). The drilling was realized with rotating steel wires using diamond paste, which took 3 – 5 minutes per hole. Drilling a hole in less than a thousandth of a second with a laser would be a real revolution in the watch stones community. In 1965 Hans Räz, director of the Watch Stones Company in Thun, was intrigued by publications on drilling of small holes into metals and crystals with ruby lasers. He mandated the Hughes company in the US to drill holes into ruby platelets, but the laser drilled holes were characterized by irregular diameters and showed craters, material ejections, and cracks. He asked Prof. K. P. Meyer to perform drilling tests at his institute. The free running ruby laser shown in Figs 2 & 3 was used end of 1965 by Hans-Peter Brändli, Max Keller, Alfred Roulier, and Michel Seehof for this purpose. The feasibility of drilling watch stones with diameters in the 50 - 70 μm range in a single shot could be demonstrated (Fig. 20), but the drilled holes were unusable for further processing.

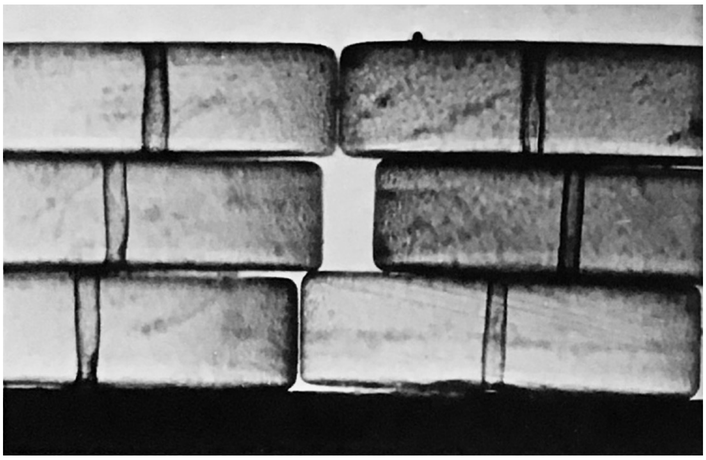


Fig. 20: 1966 experiments in drilling watch stones with ruby laser [98]

For improving the hole-quality the drilling process had to be investigated in detail. K. P. Meyer recruited Jürg Steffen, who just finished his diploma thesis on submillimetre wave gas lasers at ETH Zürich, to reinforce the project team. By observing the drilling process with a high speed camera and measuring simultaneously the input and transmitted laser light [99], it could be demonstrated that the mediocre quality and reproducibility of the drilling process was related to the poor time and mode behaviour (spatial intensity distribution) of the ruby laser pulses.

The group started investigating hole drilling with Nd:YAG-lasers. These lasers showed a TEM00-Mode intensity distribution and regular spiking (Fig. 21).

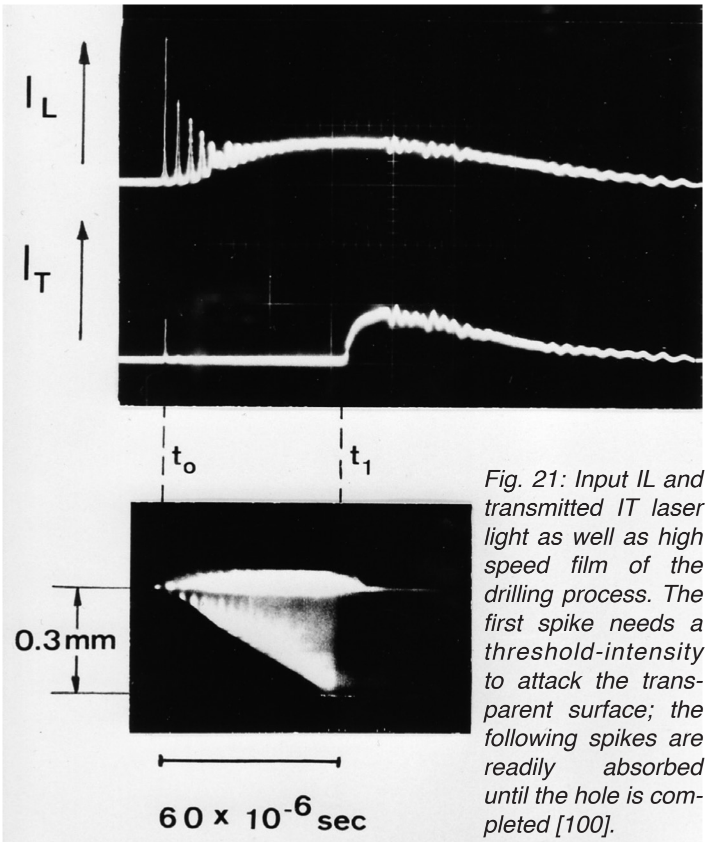


Fig. 21: Input IL and transmitted IT laser light as well as high speed film of the drilling process. The first spike needs a threshold-intensity to attack the transparent surface; the following spikes are readily absorbed until the hole is completed [100].

Drilling experiments with this laser resulted in a reproducible process (Fig. 22). Clean cylindrical holes could now be generated suitable for further processing into watch bearings (Fig. 23).

The feasibility experiments on hole drilling had been undertaken by researchers working in parallel for their thesis devoted to other topics in the laser field. They had to focus on finishing their thesis. New diploma and PhD students (Ernst Kocher, Hans-Peter Lörtscher, Lorenz Tschudi, Hans-Ulrich Leuenberger, and Lorenz Scheidegger) were hired and Jürg Steffen took over the lead of the research group. They investigated the absorption in transparent materials [101] and the design of the laser pumping unit [102]. The shape of laser drilled holes was studied in detail [103].

The development towards an industrial machine was further reinforced when Gerd Herziger took the direction of this part of the IAP and hired more personnel. New engineers and technicians (Reiner Stemme, Jürg Pulfer, Hans-Jakob Weber, and Hans Bühlmann) together with Watch Stones col-

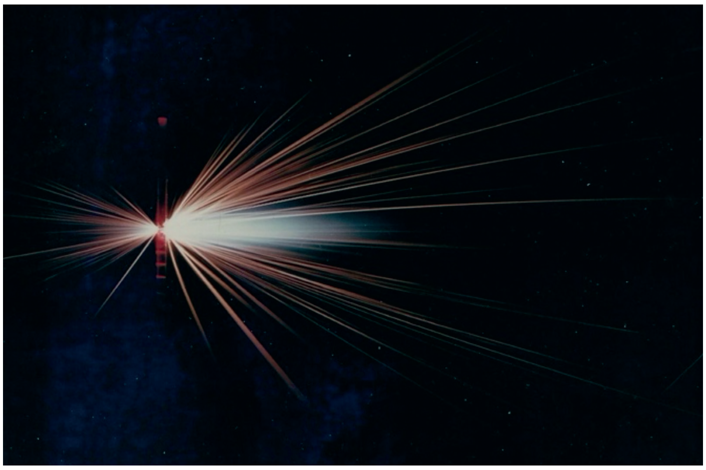


Fig. 22: Drilling process of a ruby disc viewed perpendicular to the laser beam through a polished edge of the ruby disc. Laser beam comes from right side [100].

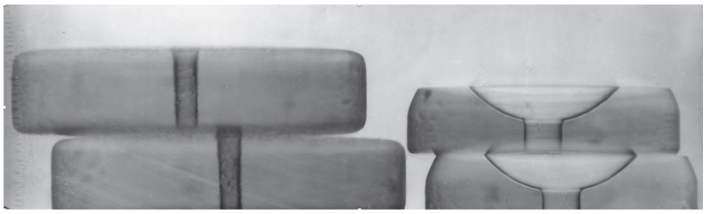


Fig. 23: Nd:YAG drilled holes (diam. 50 µm) in 0.3 mm thick ruby discs (diam. 10 mm) and finished watch bearings [100].

laborators developed a feeding machine for the ruby discs to enable series production. But new problems arose: the automatically fed discs were not drilled reproducibly, many of the discs had not been drilled at all. Up to now the discs, inserted piece by piece by hand into a chucking tool, were slightly greased on the surface. By automatic feeding this absorbing layer was missing. Such a layer had to be added before the ruby discs were ready for drilling. The beam properties emerging from the laser head and the laser resonator configuration had to be investigated in detail as function of the average power [104-106] in order to keep the thermal beam deformation at higher pulse repetition rates under control. In addition, the pump cavity [106] and the disc-feeding device had to be improved. Finally, the automatic series production at higher repetition rates became possible: In 1968 twelve discs/second could be drilled and were finished as bearings at Watch Stones Ltd. In Thun. Two years later, four laser machines had been installed drilling 50 million pieces a month (Fig. 24).

In 1972 Watch Stones Ltd, in the meantime part of the Pierres Holding group, decided to take on the original project team led by J. Steffen. The group was transferred from Bern to Thun into the "Research Institute Pierres Holding SA". Other materials processing tasks in the watch industry and associated micro-technical industries, such as, e.g., drilling of conical holes for sapphire bearings, tuning of the oscillation frequency of the quartz for the electronic watches, were investigated. In 1974 the research institute was transformed into an autonomous company named LASAG SA, led by Reiner Stemme, providing laser-based solutions for production problems in the micro-technical industries and to build and market application-specific laser equipment. Finally, LASAG AG had been integrated via Rofin-Sinar into the globally active COHERENT-Group. It's hard to believe, but in 2019, the laser-system, set up for drilling watch stones

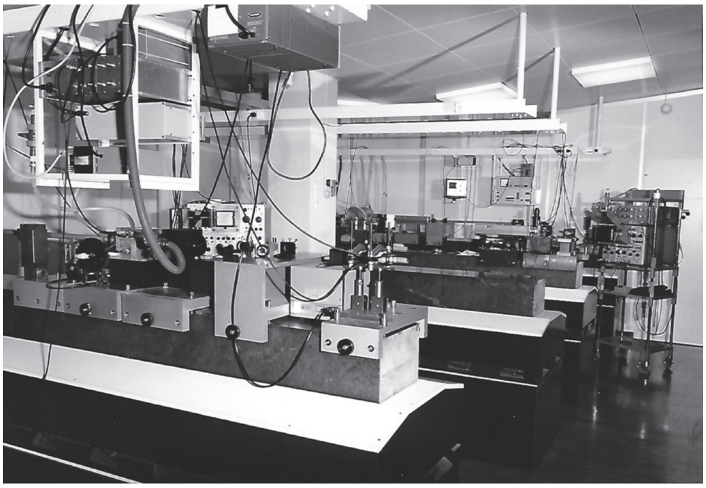


Fig. 24: Four laser installations to drill 50 Mio. ruby discs per month for watch bearings [100].

in 1970, has still been in operation in the old Watch Stones building in Thun.

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Acknowledgements:

This report could not have been written without many inputs from colleagues with whom I had the pleasure to collaborate at the time: René Dändliker, Max Keller, Theo Tschudi, Heinz P. Weber, Alfred Roulier, Jürg Steffen, Jürg Ballmer, Peter Anliker, and Reiner Stemme all contributed with comments, texts, and/or pictures material. I am grateful to Ernest Kopp and the archivist of the faculty, Niklaus Bütikofer, for their inputs on the time before and after the foundation of the Institute of Applied Physics. I am also thankful to Martin Frenz for giving me access to the depository of the Institute and to its secretary, Beatrice Thut, helping me with the archived documents.