• **Products**
  - **Single Mode Diode Lasers**
    - iBeam smart
    - iBeam smart PT
  - **Single Frequency Lasers**
    - iBeam smart WS
    - TopMode
    - Holo-Litho 405
    - TopWave 266
    - XTRA II
    - UV / RGB solutions
  - **Tunable Diode Lasers**
    - ECDL / DFB Lasers
      - CTL
      - DL pro
      - DFB pro
      - MDL pro
    - Frequency-Converted Lasers
      - SHG pro
      - DL-SHG pro
      - TA-SHG pro
      - TA-FHG pro
      - TOPO
  - **Amplified Lasers**
    - TA pro
    - BoosTA pro
    - BoosTA
  - **Laser Driving Electronics**
    - DLC pro
    - SYS DC 110: Analog Control
  - **Laser Locking Electronics**
    - DigiLock 110: Digital Locking
    - FALC 110 & mFALC 110: Fast PID
    - PDH/DLC pro: Pound-Drever-Hall
    - PDD 110/F: Pound-Drever-Hall
    - PID 110: PID Controller
    - DLC pro Lock
  - **ps/fs Fiber Lasers**
- **FemtoFiber smart**
  - FemtoFiber smart 780
  - FemtoFYb 1030-400
  - FemtoFYb 1030-800
  - PicoFYb 1030
  - PicoFYb 1064
  - FemtoFErb 1560
  - FemtoFErb 1560 FD6.5
  - FemtoFErb 1950

- **FemtoFiber pro**
  - FemtoFiber pro TVIS
  - FemtoFiber pro NIR
  - FemtoFiber pro TNIR
  - FemtoFiber pro SCIR
  - FemtoFiber pro UCP
  - FemtoFiber pro SCYb
  - FemtoFiber pro IR
  - FemtoFiber pro IRS-II

- **FemtoFiber ultra**
  - FemtoFiber ultra 780
  - FemtoFiber ultra 920
  - FemtoFiber ultra 1050
  - FemtoFiber ultra 1560

- **FemtoFiber vario**
  - FemtoFiber vario 1030

- **FemtoFiber dichro**
  - FemtoFiber dichro midIR

- **FemtoFiber customized**
  - FemtoFiber CARS
  - FemtoFiber FluoLife
  - FemtoFiber Terahertz Freeze
  - FemtoFiber OPO
  - FemtoFiber Terahertz Pump-Probe
  - FemtoFiber Quantum Microscopy

- **Terahertz Systems**
  - **Frequency-Domain**
    - TeraScan
    - TeraBeam
    - Tuning Range Extension
    - Phase Modulation Extension
    - GaAs and InGaAs Photomixers
  - **Time-Domain**
    - TeraFlash pro
    - Imaging Extension
    - TeraFlash smart
    - TeraSpeed
    - Photoconductive Switches
- **Accessories**
  - Optomechanics
  - Schottky Receivers

- **Frequency Combs**
  - DFC CORE / DFC CORE+
  - DFC Wavelength Extensions
  - DFC BC / DFC MD
  - Complete DFC Systems
  - Locking Electronics
  - DFC SDL

- **Multi-Laser Engines**
  - iChrome CLE
  - iChrome MLE

- **Customized Solutions**
  - SodiumStar
  - 633 nm High Power
  - 213 nm 10 mW cw
  - 193 nm sub-mW

- **Wavemeters & Laser Diodes**
  - Optical Isolators
    - Single-Stage TOPTICA Isolators
    - Dual-Stage TOPTICA Isolators
    - Additional Isolators
  - Wavelength Meters
  - Photonicals
    - FiberDock
    - FiberOut
    - Optical Fibers
    - FPI 100 - Fabry-Perot Interferometer
    - Compact Saturation Spectroscopy
  - Laser Diodes
    - Fabry-Perot
    - AR-coated
    - DFB/DBR
    - Tapered Amplifiers
  - ToptiCalc

- **Applications**
  - Biophotonics & Microscopy
    - High-Content Analysis
  - Industrial Manufacturing
    - Raman Spectroscopy
    - Holography
    - Computer-To-Plate
  - Fundamental Quantum Technology
    - Atom Laser Cooling & Trapping
    - Ion Laser Cooling & Trapping
    - Degenerate Quant. Gases (BEC, DFG)
- Rydberg Excitation
- Optical Pumping & EIT
- Quantum Dots & Microcavities
  - **Optical Microscopy**
    - Confocal Microscopy
    - Raman Microscopy
    - Multiphoton Microscopy
    - SHG Microscopy
    - THG Microscopy
    - Nearfield Chemical Imaging
  - **Terahertz Sensing**
    - Plastic Inspection
    - Paint and Coating Layers
    - Industrial Quality Control
    - Material Research
    - Gas Sensing
    - Hydration Monitoring
    - Ultrafast Dynamics
    - Security
  - **Applied Quantum Technology**
    - Sensing & Metrology
    - Communication
    - Spectroscopy
    - Direct Frequency Comb Spectroscopy
    - Microwave Generation
  - **Ultrafast Studies**
    - Pump-probe Spectroscopy
    - fs/ps Material Processing
    - 2-Photon Polymerization
    - Time-Resolved Microscopy
    - FLIM
    - OCT
    - Mid-IR Generation
  - **Semicon / Metrology**
    - Scatterometry
    - Inspection
    - Ellipsometry
    - Microlithography
    - Lithography Optics Inspection
  - **Astronomy & Geology**
    - Laser Guide Star
    - LIDAR Seeding
    - Distance Metrology
  - **Technology**
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- Femtosecond Fiber
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**TOPTICA Proprietary**
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- pro Series / Technology
- ultra Series
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- CHARM
- COOL
- FINE
- SKILL
TOPTICA Python Laser SDK
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TOPTICA’s tunable diode lasers have been successfully used in magneto-cardiography, the assessment of the magnetic field of the human heart. (Photo courtesy of Swiss National Science Foundation)

- Time & frequency
- Fundamental constants and tests of fundamental theories
- Atom interferometry, rotation & acceleration
- Laser-based trace gas analysis (ATTA, RIMS)
- Non-linear magneto-optical rotation for B-field measurement
- Magneto-cardiography: Measuring the heart’s magnetic field
- Magneto-encephalography: Measuring the brains (neurons) magnetic field

Metrology is one of the oldest branches of science, applied already thousands of years before Christ. People observed the movement of the sun and the moon to measure time. This allowed them to determine the best periods for seeding and for winter preparation. Time was so important that mayn cultures erected marvelous buildings, religious sites – like potentially Stonehenge – to honor their gods, the sun and the moon. Later, it became also obvious that precise measurement of time is needed for proper navigation, leading to more and more precise clocks.

Today, high precision frequency measurements on cold atoms or trapped ions give time and length standards and are improving the resolution of global positioning systems. They are used to determine fundamental constants, like the fine structure constant $\alpha$ or the Rydberg constant, and to test basic principles in physics, like the time independence of fundamental constants.
Atom interferometers are used to measure gravity (gravimeters) or rotations (gyroscopes) with highest accuracy. They can be used for earth quake and volcano eruption research, to find natural resources or hidden subterrestrial structures and to test earth tide models, the weak equivalence principle and general relativity.

Spectroscopic gas analysis is used to monitor gas flow. Sophisticated laser based methods for trace gas analysis and isotope ratio determination were developed to measure pollution, the age of ancient material or ground water and to detect plutonium production.

**Time and Frequency Measurement**

Time & frequency measurement is referred to a cesium atom standard since 1967. One second is defined as the time needed for 9,192,631,770 oscillations of the 133Cs atom's resonance frequency for its m=0 to m=0 transition between the two hyperfine levels of the electronic ground state. Consequently, the measurement is performed at microwave frequencies in a spectroscopic way that was developed by Rabi (Nobel Prize in Physics in 1944) and refined by Ramsey (Nobel Prize in Physics in 1989). First Cs atomic clocks were based on atomic beams. Newer realizations, so-called fountain clocks, use atomic fountains to increase the interaction time between the microwave and the atom cloud leading to better resolution of the time measurement.

Another way to increase the measurement resolution is to use optical or even ultraviolet transitions in other atomic elements instead of the microwave transition in Cs. This way, one second is not only divided in roughly 10,000,000,000 parts but in up to about 1,000,000,000,000,000 – an improvement in resolution of hundred thousand. In fact, present optical atom clocks based on trapped ions or atoms in optical lattices achieve typical uncertainties of 10-15 to 10-16. At present, the two clocks with highest resolution are based on ion traps of mercury (Hg+) or aluminum (Al+) and achieve uncertainties of 10-17. Such clocks would be wrong by only second in more than 3 billion years! No other measurement can be performed so precisely. Therefore, the present trend in precision metrology is to convert – if possible – a measurement into a frequency / time measurement.

**Fundamental constants and Tests**

Fundamental constants and tests of fundamental theories are also performed by frequency metrology, if applicable. The Rydberg constant, for example, is detected by performing high resolution laser spectroscopy of hydrogen and referring the laser frequency to atomic clocks. In order to test the time dependence of the fine structure constant (which should be zero according to presently accepted theory but astronomical observations might indicate that it is not) one can also compare different atom clocks. Other high resolution experiments try measure a non-zero electric dipole moment of the electron, eventually using heavy atoms or molecules. Again, standard model and CPT invariance predict that the EDM should be zero but it is important to test this with higher and higher accuracy. For example, there exist proposed extensions of the standard model that predict deviations from zero at levels that are only two to three orders of magnitude away from present measurement accuracy. So further testing of our understanding of nature is under way. Using very precise and stable clocks of different types, one can also test fundamental principles of special relativity,
e.g. isotropy ("Michelson-Morley tests") or velocity independence ("Kennedy-Thorndike tests") of speed of light, or even general relativity, e.g. universality of gravitational red shift. These are just a few examples of many interesting experiments, like matter-antimatter comparisons. Atom interferometric determinations of fundamental constants are briefly described below.

**Atom Interferometry**

Atom interferometry uses wave-like properties of atoms or the atom-light interaction together with the atomic internal states to measure certain quantities in an interferometric way. One detects matter wave interference or a quantum mechanical interference of internal states. An example is a so-called Sagnac interferometer to detect rotations. Using matter waves instead of laser light waves envisages many orders of magnitude higher resolution if the same interferometer area can be realized. Exploiting the photon recoil onto atoms during a (Raman-type) laser excitation, atom interferometry was used to measure the ratio $\hbar/m$, so the relation between two fundamental quantities with highest accuracy. Combining this result with other precision measurements, also a very accurate value for the hyperfine structure was obtained. An atomic fountain with clouds of free falling atoms can be used to measure the acceleration $g$ due to gravity. The measurement is performed by encoding the vertical position of the atoms in their internal state at three different times with laser induced Raman transitions. The relative number of atoms in one final internal state oscillates between one and zero depending on the phase difference between two possible atomic trajectories within this atom interferometer. Measuring this relative atom number, one can determine the phase difference and extract the value of $g$ so accurately that one can distinguish between different earth tide models. Launching two atom clouds at vertical distance, one can extract also the vertical gradient of $g$. A further extension to measure the Newtonian gravitational constant $G$ is possible by placing masses close to the atomic trajectories and detecting the influence on the interferometer phase. Similar setups can also be used to measure the gravitational red shift or to detect whether different objects fall in exactly the same way under gravity and hence test the weak equivalence principle.

**Gas Analysis**

Laser-based trace gas analysis makes use of the narrow linewidth of lasers to selectively interact with only one gas or even with just one atomic isotope. Monitoring the absorption or the fluorescence obtained with a laser that is tuned to the proper wavelength one can either detect the density of a gas or monitor its flow. For trace gas analysis with increased isotope selectivity, one can modify the standard IRMS (isotope ratio mass spectroscopy) method which uses segment magnets to separate the paths of different isotopes and then detects their relative occurrence. Instead of a filament based ionization of all isotopes, one uses a narrow linewidth (diode) laser to selectively ionize individual isotopes before they enter the mass filtering element. This way, isotope selectivity up to 10^{13} was demonstrated. Atom trap trace analysis uses magneto optical traps in order to (isotope-selectively) accumulate also isotopes with very low abundance.
Small Magnetic Field Measurements

Measurement of smallest magnetic fields is very difficult. The commonly used method relies on SQUIDs (superconducting quantum interference devices) that are based on superconducting material. Since superconductivity is observed only at very low temperature – even “high temperature superconductivity” is observed only below 150 K (-123°C) – these detectors are complicated and expensive. Over the last two decades, another technique was invented and turned out to be very promising. This technique uses a sample of atoms within a glass cell and a laser beam to optically pump the atoms into a special magnetic state. This way one can “polarize” the atoms to a very high degree such that their magnetic moments point into a certain direction. A second laser beam with linear polarization is sent through the sample. Depending on the atomic polarization, the laser polarization experiences a rotation (“non-linear magneto-optical rotation”) which can be detected precisely. A magnetic field – e.g. the one that is to be measured – will lead to disturbance of the atomic polarization and can hence be measured.

The applications of such laser based magnetic fields measurement are manifold. They are used to monitor earth’s magnetic field and – if placed on a plane – its variation in the atmosphere. Clinical/medical applications are magneto cardiology and magnetoencephalography. Both are based on the assessment of the body’s magnetic fields and provide more sensitive tools to detect the onset of pathological changes than bioelectric measurements.

TOPTICA’s added value

The high precision measurements that are mentioned here require tunable lasers, most of the time with very narrow linewidth and long term stability. In addition, special electronics modules are needed to perform reliable and most advanced laser stabilization. Photonicals – additional laser related accessories – help to characterize or to manipulate the laser light. Many, if not most experiments mentioned here already successfully use our products. TOPTICA Photonics is proud of its company slogan “A passion for precision.” which since many years describes very well our internal motivation. We are always open for discussions concerning special solutions, are proud to have strong relations to many national institutes or university laboratories and even take part in common research projects related to precision measurements. The pro technology, our latest revolutionary invention, allows us to produce tunable lasers with highest acoustic stability and narrow linewidth that at the same are long term stable and easy to use. The pro series products will allow you to perform the next step in resolution. We provide the lasers needed to optically pump and polarize the atoms and to measure the non-linear magneto-optical rotation. These lasers have to be tuned to the atomic transition and frequency stabilized precisely. This can easily be accomplished by using TOPTICA’s fiber coupled compact saturation spectroscopy modules (CoSy) for rubidium (Rb), potassium (K) or cesium (Cs) together with the digital control module DigiLock.

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- Related Literature
- Related Applications
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- Brochure: Scientific Lasers
- Application note: Biomagnetic Measurements Benefit from Laser Know-How