Raman frequency conversion of spectrally tunable laser radiation on coherently driven molecular vibrations in high-pressure hydrogen

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Stimulated Raman scattering (SRS) is traditionally used for an extension of the spectral range of lasers to those regions where direct laser generation is difficult or not available. The method has found its applications in optical spectroscopy where it is used to expand a spectral tunability of dye and Ti:Sa lasers, workhorses for experiments in the visible and near infrared. This is achieved via down frequency conversion of the laser radiation in low-molecular-mass gases by cascade generation of several Stokes spectral lines. Being well established at the pico- and nanosecond time scales, such an approach enables converting efficiently the laser power to first Stokes orders in the near and short-wave infrared regions. However, high-order Raman Stokes generation in the mid-infrared remains relatively low efficient. Several proposed ways for increasing efficiency in this range, namely by making use of hollow waveguides [1], capillaries [2], and photonic crystal fibers [3], have not been widespread so far because of their technological difficulties or restricted applicability.

In this work, we apply a bifrequency pump scheme of the Raman converter to boost its frequency-tunable output in the mid infrared. In the proposed approach, a high-power auxiliary laser operating at some fixed wavelength drives coherently molecular vibrations in high-pressure hydrogen gas via the SRS. Tunable many-order Stokes and antiStokes Raman generation occurs due to the four-wave mixing of a dye laser radiation with the auxiliary laser and its Raman-shifted sideband. Numerical simulation and proof-of-principle experiment under the biharmonic pump have demonstrated threshold-free conversion of the Nd:YAG laser fundamental harmonics into the first Stokes beam when the frequency-doubled Nd:YAG laser pulses are used as the auxiliary pump. The method has then been adapted to Raman frequency conversion of the dye laser (SIRAH PrecisionScan, DCM/DMSO and Pyridine1/ethanol solutions) and enabled tunable generation of a comb of the Stokes and antiStokes lines in the 355-5865 nm wavelength range with conversion efficiencies beyond of traditional single-pump-beam scheme.

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Simultaneous quantitative measurement of KOH, KCl and K atom with spatial resolution

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Biomass is a carbon-neutral energy and has been widely used for generating power and heat through thermal conversion processes. The release of gas-phase potassium species, mainly KOH, KCl and atomic potassium, from burning biomass fuels can introduce severe problems to boilers, such as corrosion and slagging. The potassium species in different forms have different chemical reaction characteristics. Therefore, it is essential to detect different potassium species in the combustion environment for a deep understanding. In the present work, an optical technique combining laser-photofragmentation and tunable diode laser absorption spectroscopy is developed for simultaneously quantitatively measuring the concentration of KOH, KCl and atomic potassium. Two laser sheets with a thickness of about 1 mm at wavelengths of 266 and 355 nm were adopted to photodissociate KOH and KCl molecules to generate K atoms. A continuous wave laser at 766 nm generated by a tunable diode laser passed perpendicularly through the laser sheet to detect the K atom. The measured K atom concentration was corelated to KOH and KCl concertation through a calibration process in a homogenous combustion environment where the concentration of KOH and KCl was measured by UV absorption spectroscopy. In this measurement system (see Figure 1), the spatial resolution depended on the overlap volume of the UV laser sheet and the 766 nm laser, which was evaluated to be 1 mm^3. In addition, the distribution of the KOH can be monitored through the laser photofragmentation induced fluorescence.

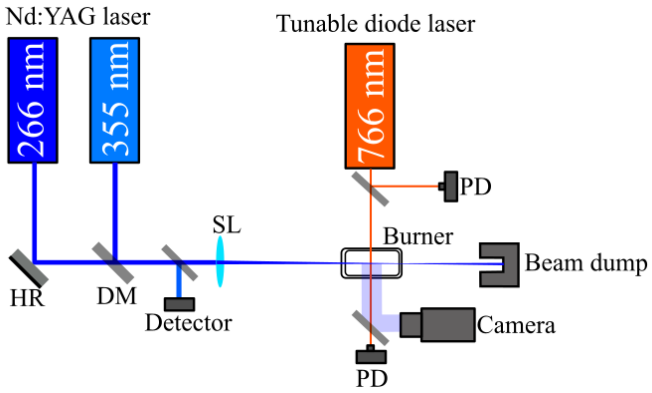

Figure 1. Optical setup for measuring the concentration of KOH, KCl and atomic potassium through PF-TDLAS.

Optical spectrophotometry for material appearance modelling in 2.5D and 3D printing

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Radiative transport equation and its solutions are actively employed in physically based rendering. Computer simulations of light propagation and light-matter interactions are beneficial for previewing the results of 2.5D and 3D prints before their fabrication. We identified main challenges of realistic modelling of the material visual appearance. Most of the polymers used in 3D printing are translucent, i.e., exhibit high light scattering and relatively low absorption of the incident light. On the other hand, new types of pigments are fabricated in a way that its reflectance properties cannot be approximated with Lambertian type. As an example, the pigments recently introduced by Merck [1] allow printing in RGBW instead of CMYK, but prediction of the resulting colours in prints requires advanced modelling due to the angularly varying spectral composition of the reflected light.
With help of the existing techniques, 2.5D and 3D prints can be visualised if the material parameters (mainly absorption and scattering coefficient, or Bidirectional Reflectance Distribution Function (BRDF)) are known. In our work, we model light propagation during the spectrophotometric measurements to retrieve intrinsic material parameters. As a result, we show an example of computer-generated visual appearance of a 3D printed object under given illumination conditions after solving the radiative transport equation including multiple scattering inside the material. Additionally, we present spectrally resolved BRDF of the RGBW inks for different concentrations of pigments and the amount of the applied ink layers. The latter results can be utilised for future applications of the reflective inks.

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Cascaded Mode-locking of Nd:YVO_4 Laser through Intra-Cavity Sum-Frequency Generation

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Ultrafast lasers have proven to be a great asset in many fields such as biological imaging [1], high-precision machining [2] and nonlinear spectroscopy [3]. This has resulted in a great interest in the further development of passive mode-locked sources. The most common passive mode-locking techniques today rely on semiconductor saturable absorbers (SESAM) [4] or other artificial saturable absorbers, such as Kerr lensing [5]. While these methods are well established, they still have issues with the durability of the SESAM or the need to reach sufficient intensities for reliable operation of the Kerr lens mechanism.

In this work we present a new mechanism for passively mode-locking solid-state lasers using intra-cavity sum-frequency generation (SFG). The underlying idea is to have two laser cavities with a shared section in which a nonlinear crystal is placed. The nonlinear medium phase-matches the SFG between the two operating wavelengths. By matching the roundtrip time of the two cavities, the same temporal part of the light in the two cavities will always interact. This forces one of the lasers to form a dark pulse and the other a bright pulse. Advantages of this approach is that it works for high repetition rates, can be used for any wavelengths in the transparency window for the nonlinear material and is easy to setup. Moreover, the phase-mismatched frequency doubling in the same crystal infer cascaded $\chi^{(2)}$:$\chi^{(2)}$ Kerr mechanism which could lead to spectral broadening and solitary mode-locking regime.

The setup is shown in Fig. 1, where two Nd:YVO_4 lasers resonate in a folded y-cavity, one operating at 1064 nm and the other at 1342 nm. In the shared section of the cavity a periodically poled nonlinear RKTP (PPRKTP) crystal is placed which is quasi-phase matched (QPM) for SFG between the two lasing wavelengths.

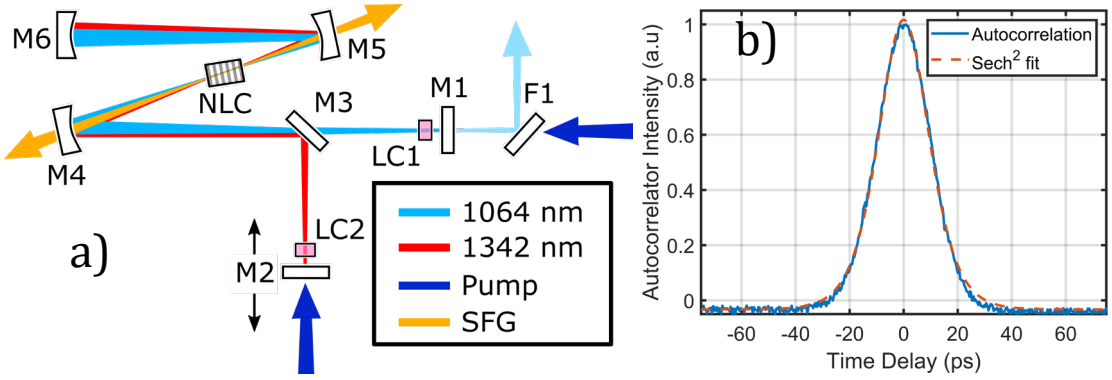

Fig. 1 a) Shows a schematic of the setup used. Where LC1 = Nd:YVO_4 with AR coating for 1064 nm, LC2 = Nd:YVO_4 with AR coating for 1342 nm, M1-M6 = mirrors for the two laser cavities, and NLC = PPRKTP with a period of 12.65 µm. Both lasers were pumped by an 808 nm laser diode. **b)** Autocorrelation of the 1064 nm pulse train, where the sech^2 fit has a FWHM of ~21 ps corresponding to a pulse width of ~14 ps.

When operating the laser, it was clear that the preferred wavelength for bright pulses was 1064 nm. One possible explanation is that in the 1064 nm laser we expect modulation instability (MI) and possible soliton formation due to action of the negative cascaded Kerr nonlinearity in the normal group velocity dispersion environment. Analysis shows that the effective Kerr nonlinearity is positive at 1342 nm. When using an output coupler of 0.4 % for the 1064 nm cavity and no output coupler for the 1342 nm cavity, a pulse width of ~14 ps was measured, see Fig.1. b. The mode-locked output power at 1064 nm was 102 mW with a repetition rate of 275 MHz.

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Coherent Control of Molecular Rotation with Single-shot fs/ns Coherent anti-Stokes Raman Spectroscopy

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Coherent anti-Stokes Raman Spectroscopy (CARS) being one of the important measurement techniques in reactive flows, we present a novel method to improve its diagnostic ability using coherent control. This is achieved by the implementation of 2- beam hybrid fs/ns rotational CARS[1,2] along with a second control pulse with a variable delay. Initially, the fs pulse involved in the fs/ns CARS process creates a rotational wavepacket. Then, if the control pulse arrives at an integer multiple of the molecular revival period (T_{rev}), a wavepacket that is exactly in phase with the initial wavepacket is created, resulting in constructive interference, i.e. signal amplification. On the other hand, if the control pulse arrives at an integer multiple of half the molecular revival period ($T_{rev}/2$), a wavepacket that is exactly in anti-phase with the initial wavepacket is created, resulting in destructive interference, i.e. signal annihilation. If the conrol pulse is equally intense as the first pulse strong signal suppression[3]is achieved. This technique can be used to improve species selectivity and measurement accuracy by selecting a delay time that is optimal for the desired purpose. The experimental evidence of this concept is shown in figure 1, in which rotational CARS signal of N_2 and O_2 molecules in air are presented.

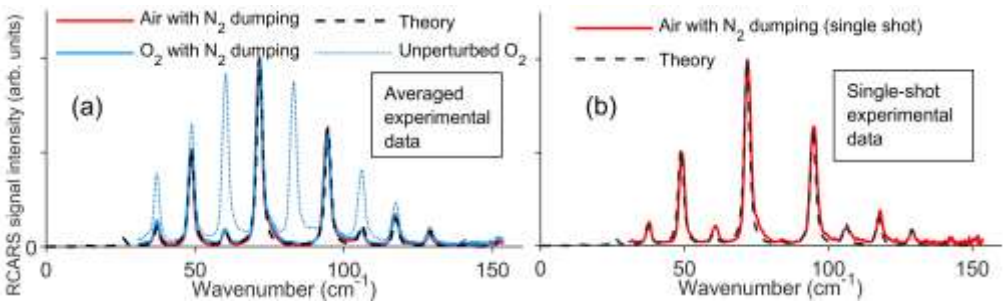

Figure1 (a) Spectra resulting from temporal integration of averaged experimentally recorded RCARS spectrograms with double-pulse excitation of air (red curve) and pure O_2 (blue curve) with t = 4.19 ps delay between the pulses. The theoretical prediction is indicated with the black dashed curve. For comparison, an unperturbed O_2 spectrum acquired with one-pulse excitation is shown with the dotted blue curve. (b) Rotational CARS spectrum of air with double-pulse excitation recorded in a single-shot acquisition (red curve), together with theoretical prediction of the signal plotted with the black dashed curve. The spectra are recorded at room temperature and atmospheric pressure and integrated after t = 25 ps, and averaged in (a) over 300 single shots.

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Non-polarizing spatial light modulation on liquid crystals for Li-Fi under normal lighting conditions

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Li-Fi, which is an optical analog to Wi-Fi, has appeared as a response to the increasing demand of larger capacity and bandwidth caused by the high number of wireless applications and users. It is often associated with the future of data communication and is one of the key aspects of a smart house and smart city. In its present state, only LED lamps are considered as such that can be used for Li-Fi transmission of visible light. The conventional solution is based on amplitude modulation where the lamp brightness is controlled with pulse-time modulated voltage.

In this work, we introduce a technique for Li-Fi that makes it possible to use any light source, that is, also discharge lamps. Modulation is carried out with a liquid-crystal (LC) spatial light modulator, made in the form of a switchable diffractive optical element (DOE). Such a modulator looks like a thin transparent plate, which is mounted in close proximity to the lamp.

In contrast to the traditional method where the average light power from the LED lamp is only half of its nominal value, the integral luminous flux in our approach is reduced only by the amount of loss associated with the Fresnel reflections from the interfaces of the LCD modulator. In principle, these losses can be compensated with the help of anti-reflection coatings.

We consider to use the following four LC modulators: 1) a phased diffraction grating operating as a beam steering device, 2) a switching DOE giving a pattern over the illuminated area, 3) a variable focus lens, and 4) an array of switching lenses. The spatial light LC-modulators can be based on photoalignment technology resulting in devices with a simple control scheme [1-3]. The conclusion about the expediency of using one or another of the modulator types in practical applications is made based on an analysis of the distribution of the light field and the modulation depth. In particular, we demonstrate that the advantages of using lenses are the absence of areas with a small depth of modulation. On the other hand, the beam steering device and the DOE generating a pattering distribution of the light enable us to obtain areas with close to 100% modulation depth.

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Optical frequency comb Fourier transform spectrometer for high-accuracy line position retrieval in the 8 μm range

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The mid-infrared wavelength range between 8 and 12 μm contains strong vibrational absorption bands of many small molecules while being largely free from interfering water absorption. This makes it important for a variety of fields such as atmospheric science or remote studies of celestial bodies. However, in order to make effective use of measured spectra for sensing applications, accurate spectral models of different molecules are required. At present, spectroscopic databases at these wavelengths are predominantly based on measurements with incoherent light sources, with line position uncertainties on the order of MHz. Significant improvements in precision and accuracy can be achieved by using optical frequency comb spectroscopy. Optical frequency combs are lasers producing broad output spectra consisting of narrow equidistant frequency modes, hence providing a combination of accurate frequency scale and broad optical bandwidth. Here, we present a Fourier transform spectrometer [1] based on an 8 μm difference frequency generation comb source [2] and a multipass cell. Using the sub-nominal sampling-interleaving scheme [3], we measure low pressure spectra of nitrous oxide N_2O, methane CH_4 and formaldehyde H_2CO with spectral sampling point spacings of ~10 MHz and 130 cm^{-1} (3.9 THz) of spectral bandwidth. Fitting the Doppler broadened absorption lines allows determination of line center frequencies with uncertainties of a few hundred kHz. For the ν_1 band of N_2O [1], we observed excellent agreement in the retrieved line positions with a previous high-precision study [4], confirming the accuracy of the system. For CH_4, a major greenhouse gas and a constituent of exoplanetary atmospheres, we determined center frequencies of over 800 lines belonging to the ν_4 fundamental band of $^{12}CH_4$ and $^{13}CH_4$ as well as two $^{12}CH_4$ hot bands, with one order of magnitude better precision than the previously available data. Including these results in a global fit of the methane spectrum yielded a strong reduction in residuals. Finally, we retrieved over 700 line center frequencies of the ν_3, ν_4 and ν_6 bands of H_2CO, a toxic pollutant, which has been poorly studied in this spectral range. This data was used for testing and verifying theoretical predictions and can be used to fill the current gaps in spectroscopic databases.

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Double-resonance spectroscopy of methane in the $3\nu_3 \leftarrow \nu_3$ region using a frequency comb probe

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Spectra of various astrophysical objects contain signatures of molecules at high temperatures (T > 1000 K). Methane in particular was the first organic molecule detected in the atmosphere of a hot-Jupiter exoplanet [1]. Theoretical models of high-temperature molecular spectra are necessary to interpret these observations. These models, in turn, need to be validated by accurate laboratory measurements and assignments of hot-band transitions. Creating gas samples at high temperatures poses an experimental challenge, and the high-temperature spectra are congested and difficult to assign. Instead, hot-band transitions can be measured with high accuracy and selectivity using double-resonance techniques. However, the use of single-frequency lasers, required for accuracy, usually implies a limited spectral coverage. We developed optical-optical double-resonance spectroscopy with a frequency comb probe to measure previously unobserved sub-Doppler transitions in the $3\nu_3 \leftarrow \nu_3$ region of methane with line position accuracy of ~1.7 MHz [2, 3]. The methane sample was contained in a liquid-nitrogen cooled single-pass cell. The pump was the idler of a continuous-wave optical parametric oscillator stabilized to a Lamb dip in a selected CH_4 transition in the ν_3 band (~3.3 μm), and the probe was an Er:fiber frequency comb, shifted to 1.67 μm using a microstructured silica fiber. The comb spectrum was detected by a Fourier transform spectrometer with auto-balanced detection. Using the sub-nominal sampling-interleaving scheme [4], we measured probe spectra covering 6 THz with sampling point spacing of 2 MHz. The measured probe transition frequencies served as the first verification of theoretical predictions in this range, and agreed within 30 GHz with the data from the TheoReTS database [3, 5]. To increase the absorption sensitivity and line position accuracy, we recently implemented a room-temperature enhancement cavity for the comb probe. Compared to the initial demonstration, the absorption sensitivity is now increased by more than two orders of magnitude, which allows detection of weaker transitions with better signal-to-noise ratios, and the accuracy of the line positions is improved to <1 MHz. We assign the probe transitions by comparing line intensity ratios measured with parallel and perpendicular relative pump/probe polarizations, and by reaching the same final state with different pump/probe configurations. The cavity-enhanced system allows the detection and assignment of new hot-band transitions, and investigation of sub-Doppler probe transition line shapes.

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Attohallen: Commissioning of a new attosecond science facility

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We present a new attosecond science facility located at the University of Gothenburg. This facility is equipped with cutting-edge femtosecond laser sources. The main source is an OPCPA-HE laser developed by Light Conversion for ELI-ALPS in Szeged based on the concepts demonstrated in Ref. [1]. It is capable of delivering CEP-stabilized sub-10 fs 50mJ pulses @100Hz. The system which we got is the prototype of a commercial version of the ELI-ALPS OPCPA laser.

This main high energy output feeds a beamline that has been built for the generation of attosecond pulses. Utilizing a loose focusing configuration (f = 10 m) [2,3], the aim of this beamline is to generate attosecond pulses/pulse trains at high flux. This new attosecond light source will then be used for ultrafast electron spectroscopy experiments on dilute targets such as negative ions, i.e. atomic and molecular systems with excess electron(s). The detection of the ejected electrons and ions will be performed using a further refined version of the world's longest (5.6 m) and most highly-resolving Magnetic Bottle Spectrometer [4].

The secondary output of the OPCPA laser, with its reduced pulse energy but substantially higher repetition rate (10 kHz), will be used for generating attosecond pulses using a much tighter focusing geometry. The output of the Pharos oscillator can also be used in combination with a harmonics module to perform pump-probe experiments with 2 mJ, 180 fs, 1030 nm @ 10kHz pulses and their 4th (257 nm) and 5th harmonics (206 nm). These outputs are already frequently used by external user groups.

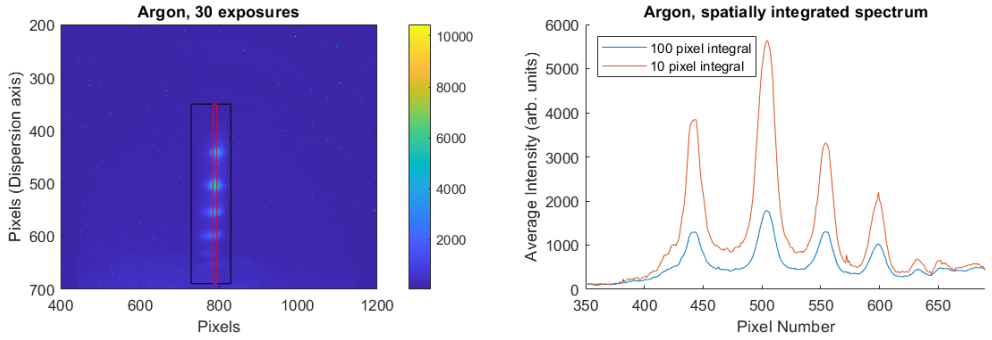

Figure 1: High-order harmonics generated in Argon at the ~10 m focal length attosecond beamline in August 2022. The spectrum is not calibrated, but all radiation below 18 eV was filtered out.

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Photonic Quantum Random Number Generation with Guaranteed Privacy

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For cryptographic applications it is not sufficient that random numbers are generated with high entropy, it is also desirable to be able to certify that the random number generator has not been tampered with by an adversary. True random numbers are a scarce resource, and quantum random number generators (QRNGs) are able to overcome the limitations of deterministic machines through the inherent randomness in quantum mechanical projective measurements. However, QRNGs are prone to detector-side side-channel attacks, either by an adversary post-deployment or already at the manufacturing stage[1]. Novel measurement device-independent (MDI) protocols loosen the hardware requirements of fully device independent schemes while still allowing for certification of the system given some assumptions[1,2]. In MDI the user is in control of the the state preparation while the measurement device is untrusted. Whenever the user wants to assert that the measurement device is operational, the user prepares and measures either of the orthogonal states which are expected to yield deterministic output from which it is possible to bound the amount of information that could have leaked to an adversary. Testing the system disrupts randomness generation and the bitrate is lowered with an increased amount of test states being prepared and measured in lieu of states used for random number generation, further motivating the need for fast switching.

In this work we show a tunable beamsplitter based on a Sagnac interferometer that demonstrates exceptional stability over 42 hours as we generate data that, following randomness extraction, pass the widely-adopted NIST 800-22 test suite[3]. We also show that we are able to dynamically switch between preparing states necessary for device testing, and superposition states for randomness generation with high contrast. This work, using all-fiber commercial telecommunication components, enables integration with existing telecommunications networks and opens up for fast self-testing of communication systems that incur low overhead costs. Further, we run a prepare-and-measure protocol where we randomly switch between preparing and measuring the quantum superposition state and either of the test states, where the probability of choosing a test state is 0.01 and the probability of choosing a generation state is 0.99. This allows us to demonstrate the long-term stability of our system. We are able to achieve a mean visibility of $0.995 \pm 1.7 \cdot 10^{-3}$ $\left[0.998 \pm 1.65 \cdot 10^{-4}\right]$ for the orthogonal state $|\Psi_-\rangle$ $[|\Psi_+\rangle]$ without removal of dark counts. As can be seen in fig. 1d, the visibilities are stable over the entire experiment duration, with less than 0.026% [0.55%] reduction over 42 hours while maintaining a mean bitrate of 246.5 ± 2.6 kbps and an average entropy of 7.2 ± 0.04 b/B while guaranteeing at least 68.8% of the generated bits to be private.

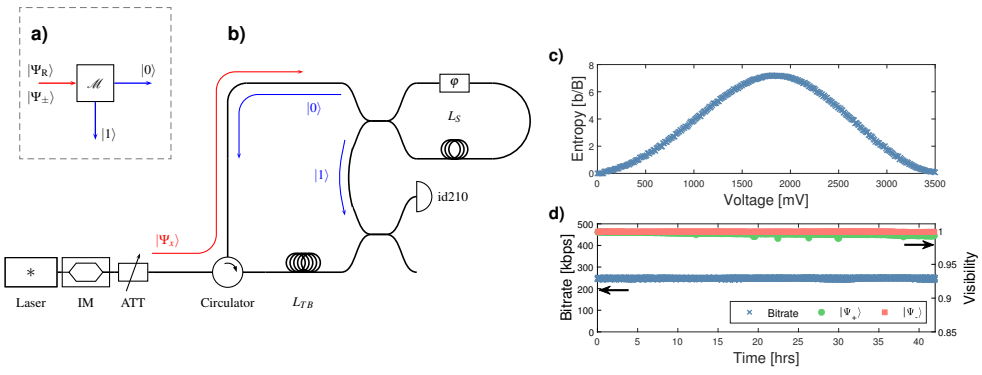

Figure 1: a) Principle of operation. b) Experimental setup. c) Entropy as a function of voltage applied to the phase modulator. d) Bitrate and visibility for teststates $|\Psi_+\rangle$ and $|\Psi_-\rangle$.

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Slow light laser stabilization

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Abstract

Ultra precise frequency stabilized lasers are core elements in modern metrology. They are used as oscillators in optical atomic clocks [1] and are integral to interferometer based tests of fundamental physics, such as gravity wave detectors. [2] The most common scheme for frequency stabilizing a laser involves locking the frequency of the laser to a stable cavity resonance frequency. The cavity consists of two mirrors separated by a distance L which the resonance frequency depends on. In this scheme, any variation in cavity length, ΔL will translate to a proportional variation in laser frequency, Δv. This change in the cavity resonance frequency can be reduced by minimizing the relative length change, $\Delta L/L$. To improve the stability either ΔL must decrease, or L must increase.

In current state of the art laser stabilization, ΔL variations are attributed to Brownian motion in the atoms forming the mirrors, and increasing L beyond a few tens of centimeters has proven to be difficult. [3] As shown in Fig. 1, any cavity length change ΔL (e.g. Brownian noise), will result in an optical path length change within the cavity. A change in cavity length will be proportional to a shift in the cavity reference frequency, which can be detected from the reflected light. During Pound-Drever-Hall locking which requires the cavity to be very stable, a shift in cavity length causes the lock point to drift. As a result, the frequency stability of the laser becomes less accurate.

By inserting a material with a low group velocity, a short cavity can be made to appear, to the light, as if it was orders of magnitude longer [4]. This has the effect of decreasing the frequency noise level by the same factor. In materials doped with rare earth ions such as Europium, a velocity reduction as large as 10^5 times can be achieved. To obtain slow light, spectral holes can be made by optically pumping all ions absorbing within a narrow interval of frequencies. Inside a spectral hole the index of refraction has a strong dependence on frequency and this has the effect of reducing the group velocity of any light wave that passes through it.

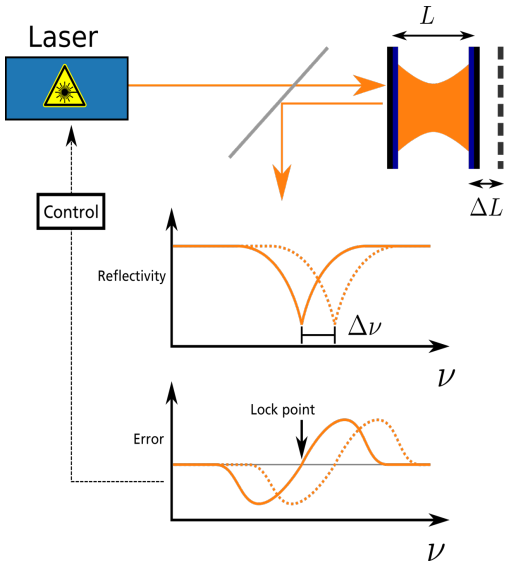

Figure 1: Length variations of the cavity during laser stabilization will cause the reference frequency to shift, which results in a drift of the error signal.

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Protocells and Surface-adhered Biomembrane Networks

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Reservoirs of lipid molecules, specifically onion shell vesicles, spread on high energy surfaces, e.g. Al_2O_3, to form a stack of molecular films (double bilayer). Eventually, the spreading lipid exhausts the reservoir, and rising tension ruptures of the films [1]. Gözen and later Köksal *et al*. discovered that this disruptive process generates a network of nanotubes, which redistributes lipid material in order to alleviate local tension (Marangoni flow), and vesicles grow from the tubes (Fig. 1 (**A**)) [2,3]. We have shown that local heating accelerate the growth and transformation of containers, and initiates their fusion. Similar processes might have occurred in warm environments on the Early Earth. Our current work aims to utilize this system and **control** soft matter **transformations with IR light** to design and construct reconfigurable chemical reaction networks (CRNs) on engineered surfaces.

In the context of the origin of life, the formation of the earliest primitive compartments and their transformation to biological cells is not known in detail, and is a subject of intensive research. Köksal *et al*. suggested the involvement of solid high energy surfaces as source of energy for autonomous shape transformations of lipid assemblies, protocell and nanotube network formation, and encapsulation of solutes therein. Such surface-supported networks of vesicles and soft nano-conduits might have functioned as primitive CRNs in the prebiotic world. Their simplicity and ease of formation inspired further development as a soft matter reactor nanotechnology. We combined an inverted laser induced fluorescence microscope with a focused 1470 nm IR-B laser and a spatial light modulator (SLM) for generating designed irradiation patterns (digital holography) in order to elevate the temperature locally at the surface and simultaneously observe lipid film transformations.

Membrane compartment formation, growth, and merging was accelerated by local heating with an IR fibre. We developed an *in situ* temperature measurement setup and confirmed consistency with conditions in warm natural environments, such as the "Lost City" hydrothermal vents (~70°C) [4]. Thermocouple absorption of IR energy was taken into account. The actual temperature in the proximity of the fibre ending (distance to the protocell) was determined by linear approximation (Fig. 1 (**B**)). We further employ thermally evaporated SiC surfaces for improved adhesion control, which allows for efficient MLV spreading into double bilayer structures and rapid growing of protocells colonies (Fig. 1 (**C**)) [5], even without additional fusogenic agents, such as Ca^{++} ions. Further research aims to implement chemical/enzymatic reactions within such networks in order to gain new insights into possible protocell development scenarios in the context of the origins of life.

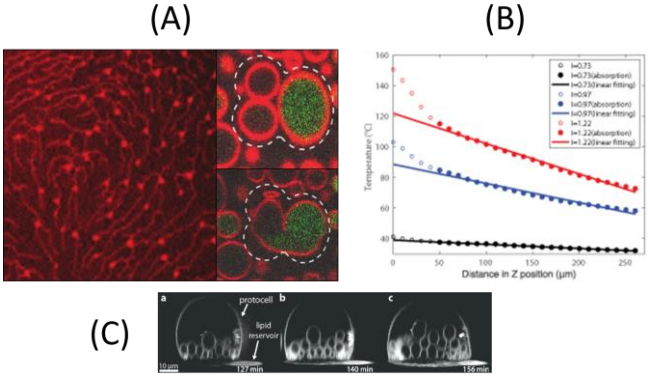

Fig. 1 The spontaneously formed nanotube network with farther development of protocells, merging of two neighbouring vesicles as a way of distribution a fluorescent material (A); temperature measured in the close proximity to the centre of IR heating (B); formation of protocells colonies encapsulated into lipid "superstructure" (C).

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Quantitative in situ detection and imaging of gas-phase K, KOH and KCl in biomass combustion

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Biomass is a renewable feedstock with a low carbon footprint, and a suitable alternative to fossil fuels for industrial thermochemical processes. However, biomass contains high amounts of inorganic compounds, foremost potassium (K), which is released to the gas phase during thermal conversion, mainly as atomic potassium, K(g), potassium hydroxide (KOH) and potassium chloride (KCl). While the K species can have beneficial, catalytic effects in some processes, they usually cause corrosion and other operational problems, thereby limiting the use of low-grade biomass in full-scale plants. To mitigate these issues, a better understanding of the K release behaviour during solid fuel conversion is needed, which requires quantitative, in situ measurements of the major gaseous potassium species.

We have recently introduced photofragmentation tunable diode laser absorption spectroscopy (PF-TDLAS) for simultaneous detection of K(g), KOH and KCl [1-3]. The technique operates in a wide dynamic range, even at optically thick conditions for K(g), as expected in gasification. The PF-TDLAS system includes pulsed UV lasers at 355 and 266 nm for fragmentation of KOH and KCl, respectively, as well as a tunable diode laser around 769.9 nm for detection of the background K(g) and K(g) fragments from KOH and KCl, and achieves sub-ppm detection limits at acquisition rates of up to 50 Hz.

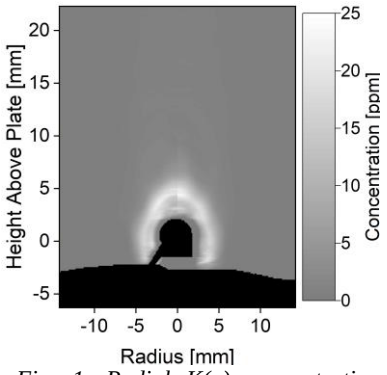

Fig. 1. Radial K(g) concentration around a biomass particle converted in CH_4/air flame.

The PF-TDLAS method has been used to measure time-resolved K species concentrations during combustion and gasification of different types of biomass in laboratory burners [2, 3], single-particle reactors and pilot-scale gasifiers [3]. A comparison of the results to thermodynamic equilibrium calculations and 0D-2D reacting flow simulations revealed discrepancies and possible knowledge gaps regarding the potassium chemistry, which motivates further studies. Time-resolved measurements of the K(g) signal decay due to fragment recombination have previously shown that, under oxidizing conditions, the decay depends on the prevailing oxygen concentration and gas temperature [4]. Here, we demonstrate that, under reduced conditions, the K(g) fragment decay is more than one order of magnitude slower and exhibits a different behaviour, possibly governed by hydrogen chemistry [3].

Employing a high-speed CMOS camera, the PF-TDLAS system has also been employed for imaging and 1D tomography of K species in laboratory flames with 120 µm spatial resolution, 28 x 28 mm field of view and acquisition rate of 100 Hz. Simultaneous, quantitative imaging of all three K species was achieved in a 4 x 14 mm field of view at a 50 Hz rate (limited by the available UV pulse energy) with a camera frame rate of 1 MHz which allowed time-resolved pixel-by-pixel imaging of the fragment decay curves, enabling reaction kinetics imaging.

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Implementing the Multi-plane Gerchberg-Saxton Algorithm in Digital Signal Processors

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Phase retrieval from intensity measurements is a widely studied field in computational optics. Despite being computationally intense, phase retrieval from diffraction patterns attracts big interest due to its simple implementation in optical systems. In our study, we investigate the phase retrieval of a one-dimensional objects by implementing them into digital signal processors. We use multi-plane Gerchberg-Saxton algorithm [1] to retrieve the phase of vectors of two-dimensional objects.

The system consists of a collimated light source, lenses, a CCD camera, a motorized translation stage, and a programmer MPLAB ICD 4 (see Figure 1). Phase maps of coma and tertiary spherical aberration were fabricated using grey-scale lithography (Heidelberg μPG 101). The grey-scale photoresist ma-P 1275G was used in the study. A slit was placed in front of the object to cut out a vector from the object. The phase was retrieved by the digital signal processor dsPIC30F6010A (Microchip) programmed in MPLAB IDE.

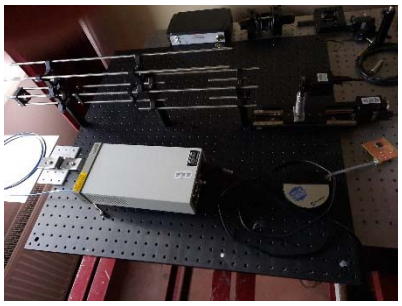
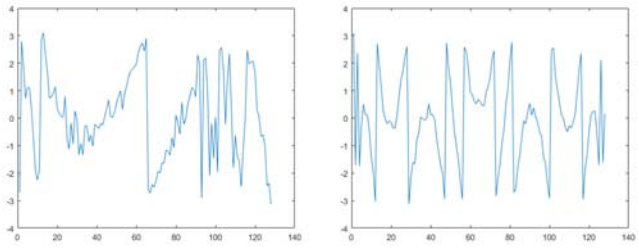


Figure 1. The system used in the study. See the text for details.

Figure 2 shows the retrieved cross sections of the mentioned aberration maps. The phase is given in radians on y axis while pixels are given on x axis. One pixel equals 30 microns. Similarity between the retrieved cross-sections and the true cross-sections can be identified. The noise can be most likely attributed to insufficient number of iterations.



The retrieved phase of coma (left) and tertiary spherical aberration (right).

In future, other phase retrieval algorithms requiring sparse input data and low signal-to-noise ratio and retrieving the phase from coded diffraction patterns [2] can be implemented in these processors. In addition, simultaneous phase retrieval by programmable logics (e.g. FPGA) could sped up these algorithms.

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GAS MODULATION REFRACTOMETRY – A TECHNIQUE FOR PRECISE AND ACCURATE PRESSURE ASSESSMENTS

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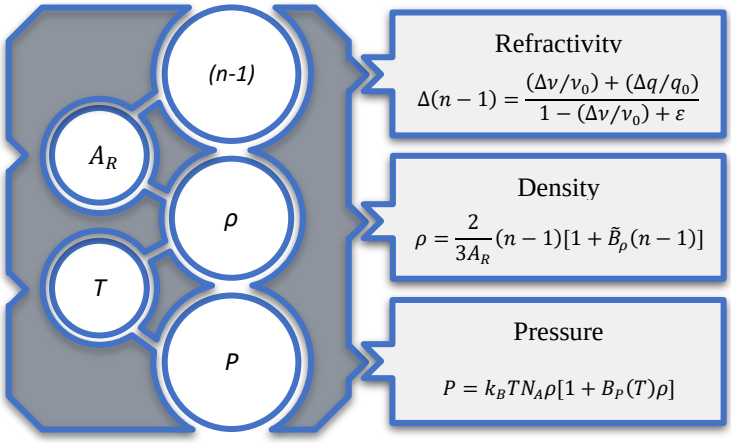
The SI unit for pressure, the Pascal, has traditionally been defined as force per unit area. One of the conventional pressure standards is the pressure balance, which generates a stable pressure by use of a piston-cylinder assembly. Weights are placed on top of the piston, which is then pushed down, with by the gravitational force, compressing the gas underneath. Under the condition that the surface area of the piston is known, this generates a well-defined pressure. These devices rely heavily on precision-made hardware that makes them costly to produce, and time consuming to maintain and operate.

In 2019, the revision of the SI-system and the redefinition of the Boltzmann constant enabled alternative means to realize the Pascal. By measuring the refractivity and the temperature of a gas, it is possible to calculate the pressure by use of the Lorentz-Lorenz equation and an equation of state.

The highest performing refractometry instruments are based on Fabry-Pérot cavities (FPC). In these, a given mode will shift its frequency by an amount, $\Delta\nu$, that is given by the refractivity of the gas, $n-1$. Since frequency is the entity that can be measured with highest accuracy in our society (~1:10^{16}), this opens up for a sensitive technique with a large dynamic range and an accuracy that, in theory, is limited only by the temperature assessment, T, and the knowledge of the molar polarizability, A_R, of the sample.



Despite these advantages, such instruments are extremely sensitive to ambient conditions; a drift in the length of the cavity of a fraction of an atomic diameter provides an error in pressure in the mPa range. This has significantly hampered the use of the technique.

As a means to remedy this, we have developed a methodology, based on a modulation of the amount of gas in the cavity, termed Gas Modulation Refractometry (GAMOR), that can significantly reduce the influence of fluctuations and drifts on assessments of pressure [1]. This has improved markedly the performance of FPC-based refractometry, giving rise to excellent performance (sub-ppm precision and uncertainties in the ppm range) [2, 3]. It has also been used to create robust and fully autonomous transportable systems that can operate outside well-controlled laboratories [4].

This poster will present a detailed background to the topic, the technology development, as well as the most recent results.

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Development of a new laser facility for material science research at Uppsala University

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The Department of Physics and Astronomy at Uppsala University is strengthening its research focus on ultrafast x-ray science with large-scale x-ray free electron lasers (XFELs) such as European XFEL and laboratory-based femtosecond laser sources. As part of this effort, FREIA laboratory is building a new femtosecond laser facility, complementary to that accessible at XFELs, for performing cutting-edge experiments in the field of material science. Techniques such as time- and angle-resolved photoemission spectroscopy (tr-ARPES) and time-resolved magneto-optical Kerr effect (tr-MOKE) will be used to get new insight into properties of non-equilibrium systems and deeper understanding transient physical phenomena including light-induced superconductivity, ultrafast charge transfer and low-dimensional material characterization.

Currently, we are implementing pump-probe experiments using a high-peak and high-average power femtosecond laser system that we already have at our disposal. The system is capable of light generation in the ultraviolet, visible, near-infrared spectral regions at several wavelengths (1.2-3.6 eV photon energy) with mean and peak power levels of up to 40 W and 1700 MW, respectively. It also provides spectrally tunable light generation in the visible, near- and mid-infrared (0.07-1.9 eV) with mean and peak power levels of up to 6.5 W and 300 MW.

In parallel, we are developing two narrowband light sources for operation in the VUV (11 eV) and XUV (up to 50 eV) regions of the electromagnetic spectrum to perform transient electronic band measurements using the time-of-flight (TOF) detector. Once being developed and combined with the existing femtosecond laser system, as well as with the tr-ARPES and tr-MOKE techniques, these sources will provide an additional and efficient laboratory-based instrument for material science experiments that we are offering to the Swedish research community. We welcome potential users and collaborators from academia and industry.

Towards 3D printed lasers

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Glass is a preferable platform for many optical devices, due to its high thermal and chemical stability as well as broad transmission window. Commonly glass is made by rapid cooling (so-called *quenching*) of its molten form. This way of fabrication is suitable for consumer products, but to achieve ultra-high purity of glass, which is used in specialized devices, other, more advanced techniques e.g., outside vapor deposition (OVD) are preferred [1]. When a complex, multi-component glass composition is required, the fabrication procedure can take up to several days, thus is not suitable for rapid fabrication and prototyping of glass compositions and devices when working towards their optimization. One example of such a composition is Er^{3+} co-doped glass, which is widely used in e.g., fiber amplifiers.

A novel approach to glass fabrication is through powder-based 3D printing [2]. In this work, a nano-powder blend, containing SiO_2, Al_2O_3 and Er_2O_3, was laser sintered into a 20 mm long, solid glass cylinder. This 3D printed cylinder was then sleeved into a quartz tube and drawn into an optical fibre. The resultant fibre had 125 µm outside diameter, with the core diameter of 4 µm. The recorded transmission spectrum of the fibre is shown in Fig. 1 (a). Transmission loss (α) of 17.2 dB/m and 23.9 dB/m was measured for λ = 980 nm and λ = 1550 nm respectively. The 30 cm long section of the fibre was then cleaved, and a pump diode laser (λ = 980 nm) was butt-coupled into the core. The fibre exhibited the full functionality expected from Er^{3+} co-doped glass, particularly an output lasing line at λ ≈ 1532 nm. The lasing was observed using back reflections from the air-glass interface at the ends of the fibre to from the laser cavity; no additional Bragg Gratings or cavity mirrors were used (see Fig. 1 (b)).

The demonstrated work shows a large potential in the powder-based glass 3D printing method. Future work includes more complex compositions and work towards rapid material tailoring, which could be considered a game changer in material science.

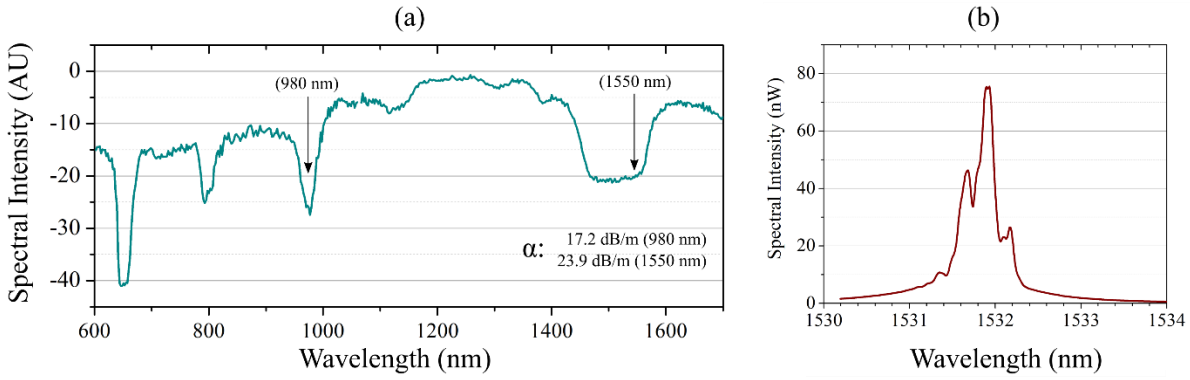

Fig. 1. Transmission spectrum (a) and loss (α) of 3D printed Er^{3+} co-doped fibre, and (b) emission spectrum upon pumping the fibre with laser diode.

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Neutron Optics: Using Magnetic Reference Layers in Neutron Reflectometry Studies to Effectively Explore Organic Matter

Neutron reflectometry is a technique that is suitable for probing the inner structure of matter and is particularly useful when studying the structure of surfaces and thin films. It enables the measurement of neutron scattering length density (SLD) which can be used to determine the chemical composition of the films.

The wave-particle duality allows neutrons to be described as waves which can also be seen from the fact that the Schrödinger equation is analogous to the wave equation of light. Due to this, many phenomena and techniques used in optics are also valid for neutrons, justifying the term *neutron optics*. That is, neutrons are often displaying characteristic optical behaviour. The common (de Broglie) wavelengths are, however, in the corresponding x-ray area where the typical optical properties of materials show weak refraction and absorption, but by using grazing incident angles, it is still possible to scatter neutrons. For instance, at an interface between two layers of a film or two media with different refractive indexes, grazing incident neutrons are effectively reflected and refracted. This means that interference can occur between waves reflected at the top and bottom interfaces of a thin film, which consequently gives rise to interference fringes in the reflectivity profile directly related to the film thickness. Due to the neutron's magnetic moment, it is in addition possible to obtain material's magnetic properties.

In optical analysis of non-trivial samples, it can be difficult to decouple parameters describing refraction and absorption, especially if layer thicknesses or other structural parameters are unknown. The problem can be resolved by *multiple sample analysis* where several similar samples, but with some parameter varied, are studied. This can for instance be done using different substrates or preparing thin films with different thicknesses. These thoughts can also be carried over to the field of neutron optics and the so-called phase problem. Since neutrons are sensitive to magnetic properties the recovery of phase information and thus the chemical depth profile of a thin film can be solved by adding a *ferromagnetic reference layer* and perform measurements with different magnetizations of this layer.

Neutrons are particularly useful for studying soft matter and in this study the aim is to investigate organic layers using the magnetic reference technique. The same organic layer is deposited on a set of film assemblies consisting of the magnetic reference layer (for instance Co, Fe or Cu) capped with a protective layer to avoid chemical degradation of the underlying magnetic material. The typical capping layer is SiO_2 which also has the benefit of being very common in neutron reflectometry experiments. In this work we have chosen lipid bilayers to be the organic material of interest and performed a series of calculations to find the optimal reference layers. The realization of the reference layers is then done using magnetron sputtering.

At a later stage will we deposit the SiO_2 capping layer and the lipid bilayer before the samples will be measured by neuron reflectometry at the facilities at Oxford (ISIS) and Grenoble (ILL).

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