一般セッション(口頭講演) | 4 JSAP-Optica Joint Symposia 2023：4.7 Quantum Optics, Nonlinear Optics and Structured Optics

2023年9月23日(土) 13:00 ~ 14:30 | A310 (熊本城ホール)

[23p-A310-1~5] 4.7 Quantum Optics, Nonlinear Optics and Structured Optics

尾松 孝茂(千葉大)

英語発表

13:00 ~ 13:30

[23p-A310-1] [JSAP-Optica Joint Symposia 2023 Invited Talk] Laser Scanning Microscope Techniques with Structured Light Beams Enabling Super-Resolution Imaging and Rapid Three-Dimensional Imaging

○Yuichi Kozawa[1], Yuuki Uesugi[1], Shunichi Sato[1] (1.IMRAM, Tohoku Univ.)

英語発表

13:30 ~ 13:45

[23p-A310-2] Femtosecond optical vortex-induced flower-shaped surface relief in azo-polymer

○Kana Ishihara[1], Katsuhiko Miyamoto[2,1], Takashige Omatsu[2,1] (1.Chiba Univ, 2.MCRC, Chiba Univ)

奨励賞エントリー 英語発表

13:45 ~ 14:00

[23p-A310-3] MW Peak Power UV laser by Fourth Harmonic Generation in $YAl_3(BO_3)_4$ crystal

○(P)Florent Cassouret[1], Arvydas Kausas[2], Pascal Loiseau[3], Gerard Aka[3], Daniel Rytz[4], Takunori Taira[1,2] (1.Inst. for Molecular Science, 2.Riken Spring-8 Center, 3.Chimie ParisTech Research Inst., 4.Coherent)

英語発表

14:00 ~ 14:15

[23p-A310-4] High Harmonic Generation from a Microplasma Source

○(D)Maria Carla Lupu[1], Filchito Renee Bagsican[1], Tatsunosuke Hanano[1], Michael Man[1], Julien Madeo[1], Keshav Dani[1] (1.OIST)

英語発表

14:15 ~ 14:30

[23p-A310-5] High-repetition rate table-top XUV source with narrow linewidth and long-term stability for time-resolved photoemission spectroscopy

○(PC)Filchito Bagsican[1], Jacques Hawecker[1], David Bacon[1], Xing Zhu[1], Vivek Pareek[1], Maria-Carla Lupu[1], Prajakta Kokate[1], Harley Suchiang[1], Michael Man[1], Julien Madeo[1], Keshav Dani[1] (1.FSU, OIST)

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Laser Scanning Microscope Techniques with Structured Light Beams Enabling Super-Resolution Imaging and Rapid Three-Dimensional Imaging

IMRAM, Tohoku Univ., ○Yuichi Kozawa, Yuuki Uesugi, Shunichi Sato

E-mail: y.kozawa@tohoku.ac.jp

The amplitude, phase, and polarization of light are the fundamental parameters that characterize light waves. In general, Gaussian beams with uniform phase and polarization distribution on the beam cross-section are mostly used in many applications using laser light beams. By contrast, when these parameters are spatially distributed on the beam cross-section, unique properties that cannot be attained by conventional light beams are manifested. Such light beams are also called structured light beams and have attracted much attention in recent years.

Radially and azimuthally polarized beams are well-known structured light beams, also referred to as cylindrical vector beams, which are characterized by axially symmetric polarization distributions. Due to the axial symmetry of polarization, vector beams exhibit distinctive behaviors when strongly focused by a high numerical aperture (NA) lens. For example, a radially polarized beam can produce a strong longitudinal electric field at the focus, which has a feature of a small focal spot compared to a conventional linearly or circularly polarized beam. This feature is particularly advantageous to enhancing the spatial resolution in laser scanning microscopy [1]. We have recently revealed that a higher-order radially polarized Laguerre-Gaussian (LG) beam can generate an extremely small focal spot, also known as superoscillation spot, by precisely controlling the incident beam size of a radially polarized LG beam on the pupil plane of an objective lens [2]. The use of the superoscillation focal spot in confocal laser scanning fluorescence microscopy enabled the significantly enhanced lateral spatial resolution approaching 100 nm even when a visible excitation beam was used.

In this talk, we will briefly review the use of structured light beams, including vector beams, in laser scanning microscopy to enhance spatial resolution. In addition, we will also introduce a new type of three-dimensional imaging technique that can be realized by controlling the spatial structure of light beams [3,4]. In this method, the depth information of samples is obtained from a single two-dimensional raster scanning of a light needle spot with an extended focal depth without the movement of the observation plane, allowing rapid three-dimensional image acquisition in laser scanning microscopy.

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Femtosecond optical vortex-induced flower-shaped surface relief in azo-polymer

Kana Ishihara[1], Katsuhiko Miyamoto[1,2], and Takashige Omatsu[1,2]
1. Chiba Univ., 2. MCRC, Chiba Univ.
E-mail: omatsu@faculty.chiba-u.jp

Laguerre-Gaussian (LG) modes, that is most commonly used optical vortices, possess an orbital angular momentum (OAM) characterized by a topological charge, ℓ, associated with their helical wavefronts, and they have been widely studied in a variety of fields, such as optical manipulations, optical-quantum communication, scanning fluorescence microscopes, and materials processing [1,2]. Surface relief formation of azo-polymers occurs through single-photon or two-photon induced trans-cis isomerization, and it has the potential to develop rewritable optical data storages with high data capacity [3].
There are several demonstrations of optical vortex induced chiral surface reliefs of azo-polymers [4,5], in which the optical vortex twists the irradiated azopolymer films to form chiral surface structures owning to OAM transfer effects. Such chiral surface structures of azo-polymers will be potentially applied to the development of ultrahigh density optical data storages with the freedom of OAM.
In this presentation, we demonstrate the formation of new optical vortex induced surface reliefs, that is flower-shaped surface reliefs with petals along the azimuthal direction, via two-photon induced photoisomerization.

The experimental setup is shown in Fig. 1. An azo-polymer film was spin-coated on a slide glass, and its thickness was measured to be ~1 μm. A near-infrared femtosecond laser (wavelength: 800 nm, pulse repetition frequency: 80 MHz, pulse width: 51 fs) was used, and its output was converted into a circularly polarized optical vortex with ℓ=1 or 2 by a spiral phase plate (SPP) and a quarter wave plate (QWP). The generated optical vortex was focused to be a diameter of ~4 μm on the azo-polymer film by an objective lens (NA=0.9). The beam power of the focused optical vortex was measured to be ~35 mW. The exposure time and laser power were then fixed to be 200 seconds and 18.7 mW, respectively.
Figure 2 shows atomic force microscope (AFM) images of structured surface reliefs. A flower-shaped surface relief with 6 or 8 petals along the azimuthal direction was then created, and its diameter and height were measured to be ~3 or ~3.6μm and ~420 or ~390 nm, respectively.

Such flower-shaped surface relief formation manifests the spatial mode instability associated with third-order nonlinear effects in azo-polymers, and it offers us a new fundamental physical insight of light–matter interaction.
Also, it will be applied to develop advanced optical data storages with new freedoms of multiple number of petals reflecting a topological charge, ℓ, of the optical vortex.

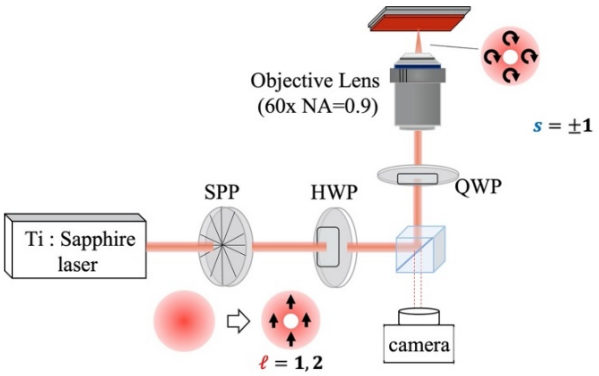

Figure 1. Experimental setup for 'flower-shaped surface relief' formation in azo-polymer film

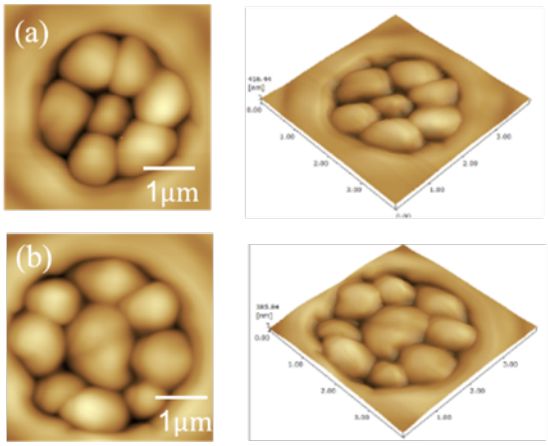

Figure 2. Surface reliefs formed by illumination of femtosecond optical vortices with (a) ℓ = 1, (b) ℓ = 2

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MW Peak Power UV laser by Fourth Harmonic Generation in $YAl_3(BO_3)_4$ crystal

Inst. for Molecular Science [1], Riken Spring-8 Center [2], Chimie ParisTech Research Inst. [3] , Coherent[4], Florent Cassouret [1], Arvydas Kausas [2], Pascal Loiseau [3], Gérard Aka [3], Daniel Rytz[4] and Takunori Taira [1,2]

E-mail: florent-cassouret@ims.ac.jp

1. Introduction

In 2008, $YAl_3(BO_3)_4$ (YAB) was reported as new non-hygroscopic material with good d_{eff} (0.63 pm/V) and small walk-off (1.9°) which can be a good alternative to the two commercial crystals: the hygroscopic $CsLiB_6O_{10}$ (CLBO) or to the β-BaB_2O_4 (BBO; which presents large walk-off) for UV generation at 266 nm [1]. However, until now the UV peak power obtained with YAB was only limited to the kW range [2]. In this work, we demonstrate 1.6 MW peak power at 266 nm using YAB as nonlinear crystal.

2. Experimental setup

The main source at 1064 nm was a Q-switched Nd^{3+}:YAG/Cr^{4+}:YAG-based gain aperture of micro-MOPA (Master Oscillator Power Amplifier). The cavity was build using 1.1at-% Nd^{3+}:YAG crystal as gain medium, a Cr^{4+}:YAG crystal (T_0 = 40%) as saturable absorber and an output coupler (OC) mirror with 50% reflectivity and it was pumped by 808 nm laser diode. The gain aperture was a Nd^{3+}:YAG crystal pumped by another 808 nm laser diode. This system improves output energy to 4.5 mJ (792 ps pulse duration) and beam quality (M^2 from 2.5 to 1.1) by amplifying the fundamental TEM_{00} mode and not the higher order ones [3]. Green laser at 532 nm (3.3 mJ, 619 ps pulse duration) was obtained through second harmonic generation with a type I LiB_3O_5 (LBO) crystal (θ = 90° φ = 11.4°). The green beam was finally focused (φ = 250 µm) inside an uncoated 2.94 mm thick YAB crystal oriented for the FHG at 266 nm (θ = 66.6° φ = 0°) (Fig. 1-a).

3. Results and discussion

Up to 423 µJ were obtained at 266 nm (268 ps pulse duration), corresponding to 1.6 MW peak power with a power conversion efficiency η of 32 % as can be seen in Fig. 1-b. This peak power is one order of magnitude higher than the 240 kW previously reported for YAB [3]. However, regarding theoretical conversion efficiency calculations, higher conversion can be expected with YAB material in these conditions. The difference comes from linear absorption ($T_{crystal}$ = 44 % at 266 nm due to Fe^{3+} impurities) but also from two photon absorption phenomena as the saturation of η increase with the pumping intensity.

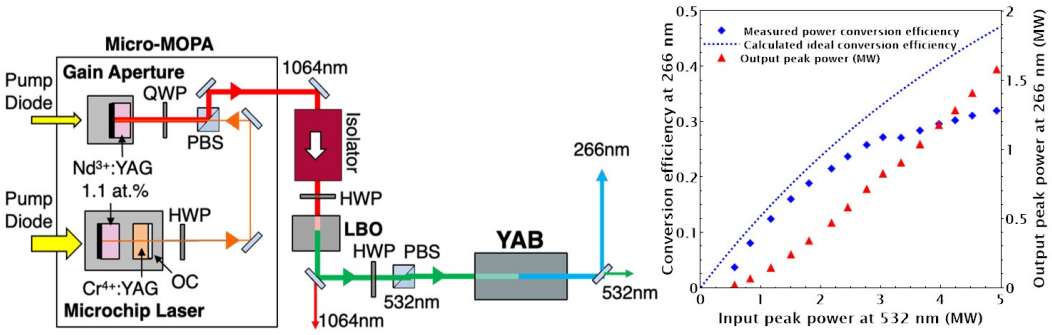

Fig. 1. Experimental setup UV light generation at 266 nm using YAB crystal (a) and obtained UV energy at 266 nm with corresponding power conversion efficiency.

4. Conclusion

Despite the limited transmission of the YAB crystal, up to 423 µJ of UV energy at 266 nm with 268 ps pulse duration were obtained by frequency conversion, corresponding to 1.6 MW peak power and 32% conversion efficiency. Further improvements are expected with the increasing of transmission at 266 nm through better growth control to open a path toward the use of longer crystals to reach >10 MW peak power. Also, two photon absorption in this material is under investigation.

Acknowledgement

This work was partially supported by Innovative Science and Technology Initiative for Security Grant Number JPJ004596, ATLA, Japan.

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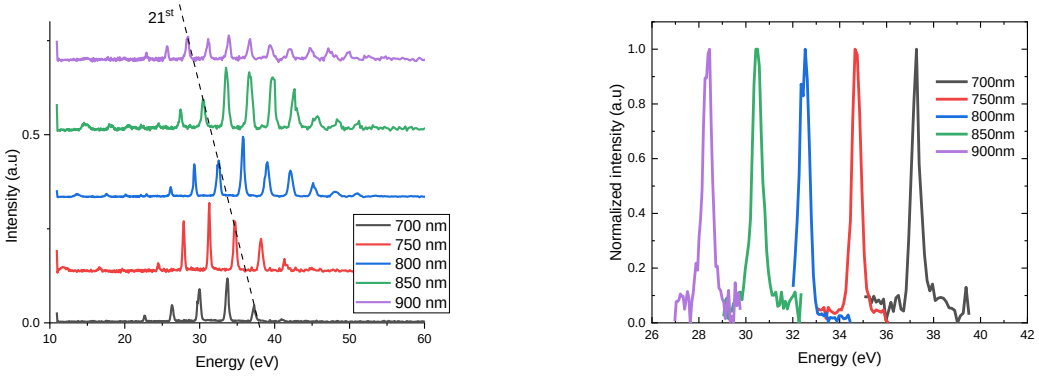
High Harmonic Generation from a Microplasma Source

Maria Carla Lupu, Filchito Renee Bagsican, Tatsunosuke Hanano, Michael K. L. Man, Julien Madéo and Keshav M. Dani

Femtosecond Spectroscopy Unit, Okinawa Institute of Science and Technology, 1919-1 Tancha, Onna son, Okinawa, Japan, 904-0495
E-mail: kmdani@oist.jp

The nonlinear process of High Harmonic Generation (HHG) has enabled table-top ultrafast sources of coherent radiation, mainly in the extreme ultraviolet (XUV) spectral region, with extensive use in a large variety of domains, such as industry [1], biology [2], and photoemission science [3]. In particular, the latter would greatly benefit from tunable high repetition rate XUV sources, to map the electronic band structure of materials over a large range of the Brillouin Zone with fast data acquisition. Generally, in HHG experiments, the required peak intensity is reached with the use of femtosecond lasers with a pulse energy in the range of 10 µJ – 1 mJ, typically focused down to a spot diameter of 10 µm – 100 µm, respectively. Focusing the beam tighter than a few microns, thus generating a microplasma, would enable the use of sub-µJ sources. However, a microplasma HHG source is expected to lead to a very poor XUV photon flux. This assumption originates from the phase matching condition in an ultra-tight focusing geometry, where the significant contribution of Gouy phase factor cannot be balanced out. Prior HHG work based on micron-scale spot diameter [4] has shown an XUV photon flux multiple orders of magnitude lower than the requirement for photoemission experiments [3]. Here, we demonstrate experimentally the high efficiency of a microplasma XUV source [5], with a photon flux that exceeds 10^{11} photons/s/harmonic, driven by a pulse energy lower than 1 µJ. As a driving source, we use a noncolinear optical parametric amplifier system operated at 4 MHz repetition rate, from which we tune the driving wavelength between 700 nm - 900 nm. In Fig. 1, we show the measured XUV spectra, with two regimes of tunability: a) a discrete harmonic tunability ranging from 20 to 50 eV and b) a continuous tunability of about 9 eV. The generation of efficient XUV radiation with sub-µJ class sources could open a new era for spectroscopy and material science.



a) b)

Fig. 1. a) Measured XUV spectra for driving wavelength varied from 700 nm to 900 nm. b) Continuous tunability of the 21st harmonic.

Acknowledgments
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High-repetition rate table-top XUV source with narrow linewidth and long-term stability for time-resolved photoemission spectroscopy

Filchito Renee G. Bagsican, Jacques Hawecker, David Bacon, Xing Zhu, Vivek Pareek, Maria-Carla Lupu, Prajakta Kokate, Harley Suchiang, Michael K.L. Man, Julien Madéo, and Keshav M. Dani

Femtosecond Spectroscopy Unit, Okinawa Institute of Science and Technology Graduate University
E-mail: kmdani@oist.jp

1. Introduction

The emergence of table-top XUV sources has ushered in a new era of multidimensional photoemission spectroscopy that allowed access to the nature and dynamics of excited states in various material systems [1]. Here we present our XUV source that operates at 2 MHz with very high signal-to-noise, long-term stability, and narrow linewidth that has been instrumental to our recent achievements in understanding exciton physics in 2D semiconductors [2-4].

2. Experimental set-up and source characteristics

Time-resolved photoemission spectroscopy is a powerful tool in studying the dynamical evolution of excited states in materials. Fig. 1 illustrates the typical scheme employed in our experiments. A portion of the output from a Yb-doped fiber amplifier is used to drive a non-colinear parametric amplifier to produce a widely tunable photoexcitation source (320-2500 nm). Another portion is used to produce XUV through high-harmonic generation (HHG) using our patented technology [5].

Our technology uses a very tight focusing of the pump laser, typically < 5µm, which allows the use of lower pulse energies (< 10 µJ) and long pulse durations (> 200 fs) to reach the required laser intensity for HHG [5]. The ability to use uncompressed pulses directly from the Yb-doped fiber amplifier greatly reduces the complexity of the experiment. Furthermore, having a small XUV source (< 5 µm) allows us to achieve a small XUV probe on the sample spot (FWHM < 10µm) with just a single XUV ellipsoidal mirror placed in a 2f-2f configuration. This is critical for studying micron-sized samples like exfoliated 2D materials.

We use 21.7 eV (9th harmonic) as XUV probe in our photoemission experiments. This harmonic is separated from the other harmonics and the excess pump laser using a set of Al and Sn filters. A Si plate set at grazing angle is then used to guide the XUV onto the sample. At typical operating conditions, we use around 7 µJ of pump laser (515nm, ~250fs pulse duration, 2 MHz repetition rate) for HHG, which gives an estimated flux of ~1 x 10^{11} ph/s on the sample and a linewidth of < 30 meV. Actual photoemission counts using this XUV source show < 3% RMS variation over a 10-hour period and < 7% for a 1 week-period.

3. Performance demonstration using 2D materials

We demonstrated the performance of our XUV source for momentum microscopy by probing the dynamics of excitons in atomically thin semiconductors [2-4]. The high-repetition rate and long-term stability of our source, in addition to the small spot size and narrow linewidth, were key to obtaining high-quality data with reasonable acquisition time. With a properly prepared monolayer semiconductor sample, our static ARPES measurements at 100K routinely show FWHM linewidths < 90 meV, which to the best of our knowledge, is the best energy resolution achieved on a monolayer semiconductor using a table-top XUV source.

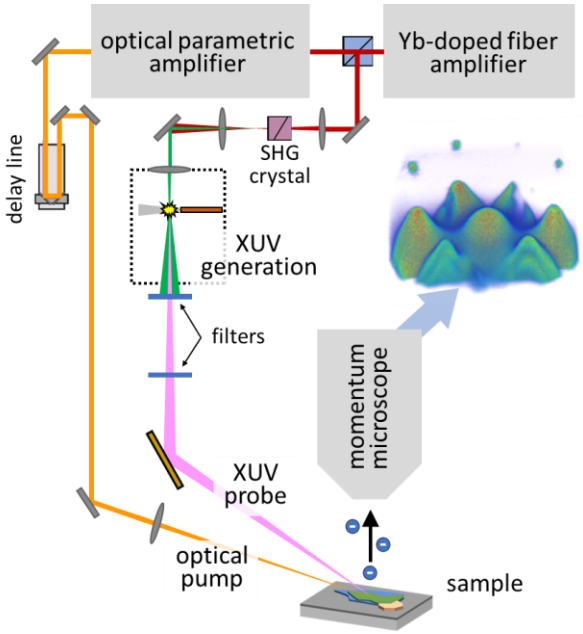

Fig. 1 Experimental set-up.

Acknowledgements

This work is supported by the Femtosecond Spectroscopy Unit – OIST Graduate University, OIST Graduate University Innovative Technology Research – Proof of Concept Program, and JSPS Kakenhi Grant Nos. JP21H01020 and JP22K18270.

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