Report on the outcomes of a Short-Term Scientific Mission[1]

Action number: CA20129

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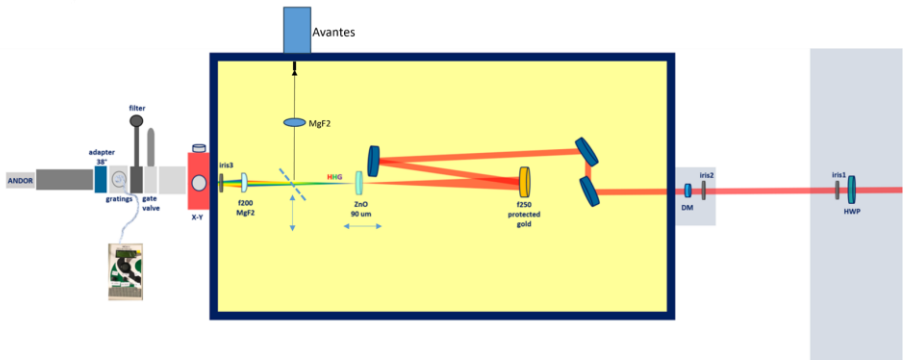
Details of the STSM

Title: Study of high harmonic generation in semiconductors irradiated by an intense mid-infrared ultrashort laser pulse

Start and end date: 18.05.2025 - 31.05.2025

Description of the work carried out during the STSM

The experiment was conducted using the MIR laser source at ELI-ALPS using the arrangement shown in the figure below.



Linearly polarized carrier-envelope-phase (CEP) stable few cycle MIR pulses of ≈ 45 fs duration and carrier wavelength of $\lambda_L \approx 3.2$ μm were used in a OPCPA (optical parametric chirped-pulse amplifier) architecture at a repetition rate of 100 kHz and of maximum energy 120 μJ. The beam waist at the focus was measured at 45 μm. This laser system enabled the generation of high harmonic orders (HO) from N= 2 to 19 (HO2 to H19) in the chosen crystalline solid samples readily measurable with standard spectrometer in ambient air and with an VUV spectrometer under vacuum. The high harmonic generation experiments was performed in transition geometry. Power scans revealed that the typical energy for producing the harmonics in our experiment is 1.8 μJ. When using an a-cut ZnO crystal (crystal orientation 11-20) both odd and even harmonics were generated for laser fields polarized along the c-axis of the samples of thickness 50 μm and 200 μm. Odd harmonics were obtained for a c-cut ZnO crystal (crystal

[1] This report is submitted by the grantee to the Action MC for approval and for claiming payment of the awarded grant. The Grant Awarding Coordinator coordinates the evaluation of this report on behalf of the Action MC and instructs the GH for payment of the Grant.

orientation 1000) for laser field polarized along the optical axis of a sample of thickness 50 μm. In Si thin films of thickness 50, 100 and 200 nm with crystallographic orientation [100] only odd harmonics were observed during irradiation. Two different spectrometers – one in the VIS-UV spectral range and one in the VUV spectral range equipped with a CCD camera were used. To explore the crystal structure of the samples via the orientation dependence of the generated high harmonics we varied the laser polarization by a half-wave plate and a quarter-wave plate. The control of the measurements and the data acquisition from the spectrometers, cameras, and motorized rotation stages for the samples and for the half wave plate and quarter wave plate was done by a software. A manual Z scan was performed as well. A TIPTOE characterization of the laser profile was performed as well.

Description of the STSM main achievements and planned follow-up activities

One of the main achievements of the experimental campaign was the commissioning of the detection of the high harmonics in VUV spectral range. A new grating for the VUV spectrometer was installed and tested. Thus, we were able to detect above-gap harmonic spectra in the chosen semiconductors (up to the 20 th harmonic order). The measurements of the high harmonics with the VUV spectrometer were performed in vacuum.

The orientation dependence of the odd order and even order harmonics is clearly revealed in the experimental results. These experiments demonstrated a strong link between the band structure of a crystalline solid and the dependence of the generated high order harmonics on its crystallographic orientation in respect to the polarization of the irradiating intense femto-second mid-infrared (MIR) pulses. The polarization mapping observed for below band gap and above band gap harmonics generated from ZnO and Si could originate from their band structure, which strongly impacts the emission mechanisms. This will be further analysed theoretically and comparison with experimental results will be made.

The analysis of the experimental results is in progress. It is expected to start the preparation of a manuscript together with members from the MIR laser group at ELI ALPS.