Current and planned future experiments with relativistic high harmonic generation using the JETI200 laser

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High-order harmonic generation (HHG) through nonlinear interaction of intense laser beams with different systems is a promising source of bright, ultra-short bursts of extreme-ultraviolet radiation. High harmonics arise since the radiation is emitted as a train of attosecond pulses. A key objective is to achieve a single isolated pulse to allow time resolved measurements characterized by these pulses on an attosecond scale. We carried out experiments into JETI200 facility in Jena, Germany in order to characterize the properties of the harmonic radiation generated from a solid surface interaction, with the ultimate goal of employing temporal gating schemes to reduce the attosecond pulse train to a single pulse. The reason this laser is well suited for such experiment is a combination of its high power and the fact it is "quasi"-few-cycle(6.39 cycles) ideal for trying out gating scheme.
Single attosecond pulses are possible from JETI200 under Oblique Incidence Condition

Relativistically Oscillating Mirror

HHG from solid surfaces can be appreciated from the 'moving mirror model' as described by von der Linde [1] and Lichters [2]. In conformity to this model, when a femtosecond laser pulse interacts with a solid surface, it can produce very short scale length plasma. During the short interaction time with the laser pulse, the ions can be accounted as fixed positive background charges. Electrons in a skin depth layer experience strong electromagnetic forces and are driven back and forth across the vacuum boundary. The details of the electron spatial distribution are rejected and electron motion is described by the movement of the critical density surface (i.e. the reflecting surface or the "mirror"). This effective reflecting surface corresponds to the moving mirror.

Non collinear polarization gating

A recently demonstrated method of temporally gating attosecond pulse trains generated through the ROM mechanisms is to use two circularly polarized parallel non collinear laser pulse, characterized by opposite handedness and a controlled delay. After focusing there will be a spatial overlap between the beams which can they interfere, it will be linear polarization at the point of temporal overlap where the pulse have similar intensity. For driving mechanisms that are suppressed by elliptical polarized pulses this gates the attosecond emission to the period when laser polarization is linear, this is the commonly used polarization gating.

When laser is circularly polarized and at normal incidence on the surface, isn't an oscillatory motion of the electrons perpendicular to the target surface. Absence of oscillation leads to suppression of ROM mechanism and therefore is suitable for polarization gating[4].

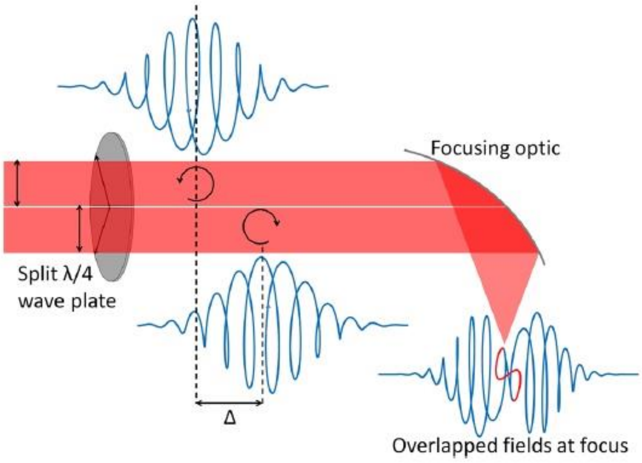

Figure 1: Sketch of the noncollinear polarization gating method. A split quarter wave plate with orthogonal optical axes converts two delayed linearly polarized half beam pulses into left and right circularly polarized pulses. These pulses overlap at focus and create a linear gate.

Before to introduce equations it is important to explain main principle of noncollinear optical gating [5].A temporal delay between two few-cycle pulses brings to rapidly changing amplitude ratio between subsequent half cycles. Since the direction of the resulting attosecond pulses depends on the weighted average of the individual wavevectors, overlapping these pulses noncollinearly causes a temporal rotation of the wavefronts as the relative field amplitude changes hence the attosecond pulses generated from subsequent half-cycles are emitted in different directions

The width of the linear gate for each gating scheme can be shown to be, respectively for polarization gate $\boldsymbol{\delta t_{PG} \approx 1.44 \xi_{th} \tau^2}/\Delta$, while for the noncollinear $\boldsymbol{\delta t_{NC} \approx 1.55(\Theta/\gamma)}$ $(\boldsymbol{\tau^2}/\Delta)$. Combining both equations, there is final expression for the combined gate.

$$\delta t \approx \left(\frac{\delta t_{PG}^2 \delta t_{NC}^2}{\delta t_{PG}^2 + \delta t_{NC}^2}\right)^{\frac{1}{2}} \qquad Eq(1)$$

ξ_{th}=0.27, and was found to be a best fit for threshold ellipticity, in a previous experiment at an angle of incidence of 22.5 ° and laser intensity of $6 \times 10^{19} Wcm^{-2}$,which is defined as the value for which relative signal is 10%; τ is the pulse duration; Δ is relative delay of pulses; Θ is divergence of the pulse and γ is the angle that the wave front of each half beam makes with the center axis. It is valuable to note that (τ^2/Δ) is present in both equations of gates.

Important considerations are that shorter gate arises from larger pulse separations but that also reduces the intensity in the gate. Combining the two gating methods reduces the requirements on the pulse separation allowing us to achieve a higher gate intensity.

Plan of non collinear polarization gating

It is key to characterize ellipticity dependence of harmonic emission for magnitude of all orders. Subsequently is observed spectral width of orders (sign of temporal gating) as the timing of the beam halves is varied (the gate is shorter as the beams are more separated).

Table 1: Calculated values of pulse separation and relative intensity

Gate	Pulse Separation (Laser Cycles)	Relative Intensity at gate
Total (OBL INC)	8.34	0.304582
Total (NOR INC)	16.7	0.008607
PG (OBL INC)	11.73	0.095774
PG (NOR INC)	23.40	8.78E-05
NC (OBL INC)	11.92	0.088443
NC (NOR INC)	23.79	6.4E-05

In the table there are calculated values for separation pulses in Polarization gating, Non collinear and also combined gate. Through Δ, separation of the pulse, is also possible evaluate separation of cycle, for Oblique and Normal incidence. Is interesting to note that for a pulse with limited duration, intensity is higher. Relative intensity at gate is calculated because if increase pulse separation, gate is shorter and also intensity is lower. Good values of intensity, instead, permit to drive mechanism. Simulation show for angle of incidence of 15° and below, ellipticity threshold is constant and equal to 0.2[4]. In conclusion it will be difficult to work with Normal Incidence because of stricter requirements on the gate width as two pulses are generated each cycle, instead Oblique incidence, close to Normal Incidence with 15 or 20 degree should be possible in facility JETI200.

References

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