Concept for producing "extreme" surface plasmon polaritons

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Single Cycle Surface Plasmon Polaritons?

- Nowadays it is possible to generate optical pulses of near-single cycle duration (few femtoseconds) basically via nonlinear processes

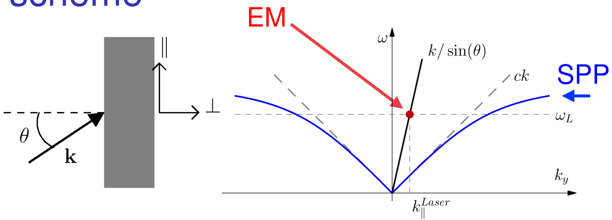
$\longrightarrow$ Can we generate single cycle surface plasmon polaritons (SPP) for ultrafast applications in plasmonics *without* using a single cycle laser pulse as a driver?

- The proposed concept exploits a "standard" laser pulse with wavefront rotation in the grating coupling scheme for SPP generation

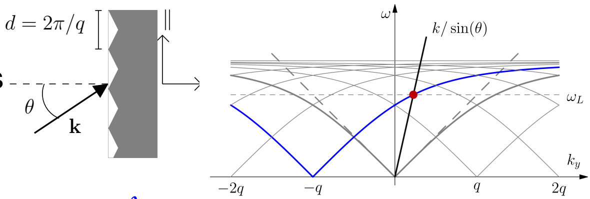
Grating coupling scheme

No matching with EM wave at a plane interface:

$\omega = ck = ck_{\parallel}/\sin\theta$



Periodic grating: "replica" (*) of $\omega_{SP}(k_{\parallel})$ enables matching

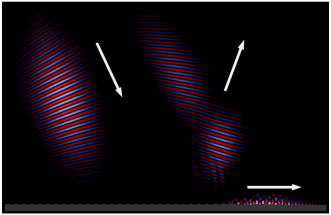


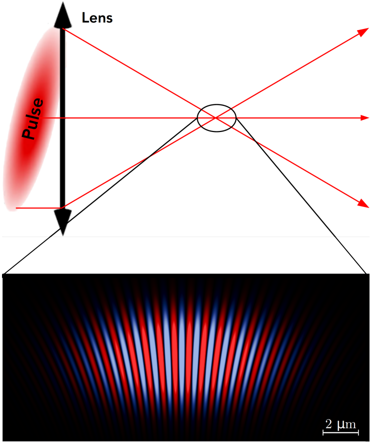
"resonant" angles: $\sin\theta \simeq n\frac{\lambda}{d} - 1$

(*) folding in the Brillouin zone – Floquet-Bloch theorem

In-pulse rotation of incidence angle

Inducing wavefront rotation (WFR) in the laser pulse the effective incidence angle rotates in time $\longrightarrow$ "resonant" condition holds only for an interval only shorter than the driving pulse



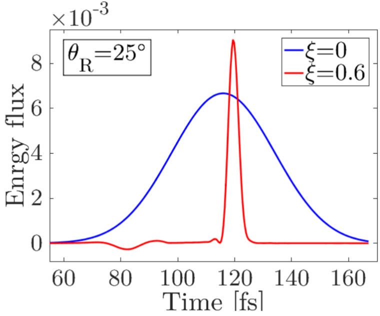


WFR obtained by focusing a tilted wavefront pulse

A near "single-cycle" SPP

MEEP[1] simulations of
WFR pulse on Ag grating

SPP w/o and with WFR
duration: 3.8 fs (~ 1.4 cycles)

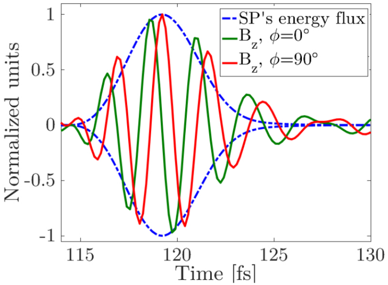


$E = E(r,z,t)\exp(-i\omega_L t + i r \xi t + \phi)$

ξ : WFR parameter

laser: 30 fs , $\lambda_L = 0.8\ \mu m$

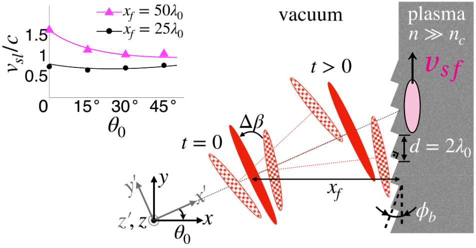
dependence on
absolute phase ϕ



[1] http://ab-initio.mit.edu/wiki/index.php/Meep

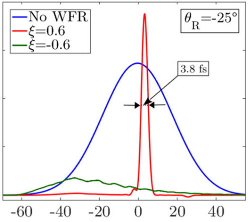
WFR enhancement of SPP amplitude

"Sliding focus" effect: WFR makes the laser spot move along the target with velocity



$$v_{sf} \simeq \frac{\Delta\beta\, x_f}{\lambda \cos^2\theta_0} \propto x_f \xi$$

(x_f: waist-to-target distance)

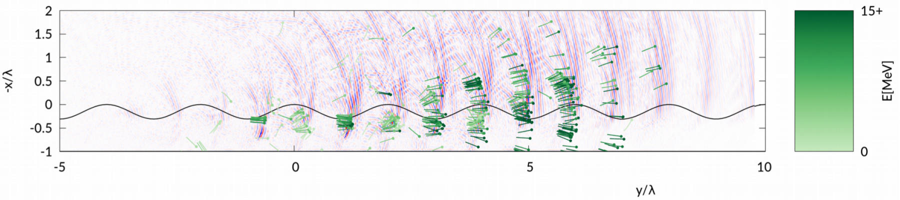


When $v_{sf} \simeq c$ the SPP is "sustained" along its propagation: increase of peak amplitude

(Note the effect of the sign of ξ)

SPP in "extreme light" regime

When excited by fs, ultra-high intensity ($> 10^{19}$ W cm^{-2}) laser pulses SPPs produce multi-MeV, 100's-pC electron bunches via "surfing" acceleration and spatio-temporally correlated bursts of XUV high harmonics via a sort of "free electron laser" effect.



Particle-In-Cell (PIC) simulations by L. Fedeli
Experimental observations: L. Fedeli et al, Phys. Rev. Lett. **116** (2016) 015001; G. Cantono et al, Phys. Rev. Lett. **120** (2018) 264803

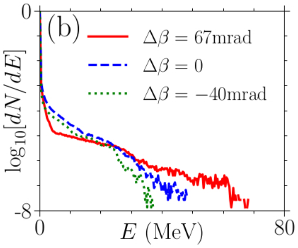
WFR effect for “extreme” laser pulses

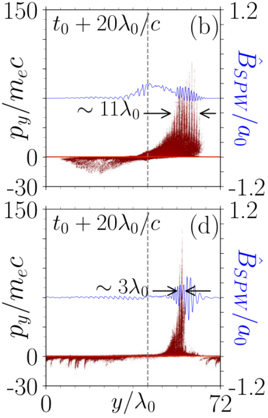
SMILEI open source PIC code

27 fs & 4×10^{19} W cm^{-2} laser pulse

WFR may double the cut-off energy of the electron bunch while shortening its duration down to 8 fs

(simulations by S. Marini and P. Kleij)





waiting for experiments . . .

References

- F. Pisani, L. Fedeli, A. Macchi,
  Few-cycle Surface Plasmon Polariton Generation by Rotating Wavefront Pulses,
  ACS Photonics **5**, 1068 (2018)
- A. Macchi, G. Cantono, L. Fedeli, F. Pisani, T. Ceccotti,
  Extreme high field plasmonics: electron acceleration and XUV harmonic generation from ultrashort surface plasmons,
  Phys. Plasmas **26**, 042114 (2019)
- S. Marini, P. S. Kleij, F. Pisani, F. Amiranoff, M. Grech, A. Macchi, M. Raynaud, C. Riconda,
  Ultrashort high energy electron bunches from tunable surface plasma waves driven with laser wavefront rotation,
  Phys. Rev. E **103**, L021201 (2021)