Quantum Pathways Interference in Photoemission from Biased Metal Surfaces Induced by Two-color Lasers

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I. Motivation

- Two-color coherent control of photoemission from nanotips has drawn great interest. It has flexibility in manipulating electron dynamics in ultrashort temporal scale and nanometer spatial scale.
- By tuning the intensity mixture ratio and relative phase difference between the fundamental laser and its second harmonic, the photoemission current can be modulated with a contrast (called visibility or modulation depth) of up to 97.5%.
- DC bias is another key tuning knob.
- The underlying physics that how laser fields and dc bias field influence two-color coherent control of photoemission is still unclear.

II. Models

\[ W_0; \text{nominal work function} \]
\[ E_F; \text{Fermi energy} \]
\[ E_{\text{vac}}; \text{Vacuum level} \]
\[ F_\perp; \text{DC field} \]
\[ \omega; \text{Fundamental angular frequency} \]
\[ W_{\text{Schottky}} = 2e^2F_\perp/16\pi\varepsilon_0; \text{Schottky barrier lowering} \]

- Potential profile

\[ \phi(x,t) = \begin{cases} 0, & x < 0 \\ V_0 - eF_\perp(x - x_0), & x \geq 0 \end{cases} \]

where \( V_0 = E_F + W_0 - W_{\text{Schottky}} \), and two-color lasers \( f(t) = F_1 \cos(\omega t) + F_2 \cos(2\omega t + \theta) \)

- Electron transmission probability

\[ D(\tau) = \sum_{n=0}^{N} w_n(\tau) \]

- Quantum pathway interference model

\[ D_{\text{I}} = a^*(\begin{pmatrix} F_1 & F_2 \end{pmatrix})^*(\begin{pmatrix} a & a \end{pmatrix}) \]
\[ D_{\text{II}} = a^*(\begin{pmatrix} F_1 & F_2 \end{pmatrix})^*(\begin{pmatrix} a & a \end{pmatrix}) \]
\[ D_{\text{III}} = a^*(\begin{pmatrix} F_1 & F_2 \end{pmatrix})^*(\begin{pmatrix} a & a \end{pmatrix}) \]

- When \( F_2/F_1 \) increases, emissions through pathway II and interference II&III become the dominant terms.

III. Fourier series expansion

\[ F = 2.6 \text{ V/mm}, F_\perp = 0 \]

\[ D(\tau) = \frac{C_0}{2} \sum_{n=1}^{N} c_n \sin(n(2\omega t)\tau + \phi_n) \]

with \( c_0 = \frac{1}{T} \int_{0}^{T} D(\tau) \, d\tau \), \( c_n = \sqrt{a_n^2 + b_n^2} \), \( a_n = \frac{1}{T} \int_{0}^{T} D(\tau) \cos(n(2\omega t)\tau) \, d\tau \), and \( \phi_n = \tan^{-1} \left( \frac{a_n}{b_n} \right) \).

IV. Effects of laser fields

When \( F_2/F_1 \) increases, emissions through pathway II and interference II&III become the dominant terms.

V. Effects of dc field

- Dc field enhances electron emission
- There are two peaks on visibility
- Interference is sequentially suppressed as dc field increases

VI. Conclusion

- We analyzed the quantum pathways interference in two-color coherent control of photoemission using exact analytical solutions of the TDSE including dc bias.
- Increasing the intensity ratio of the second harmonic to fundamental lasers would result in more contribution from multicolor pathway and multiphoton absorption of M2a.
- Increasing bias voltages sequentially decreases the weights of higher order 4\( \omega \) and then 2\( \omega \) components, resulting in two peaks in the visibility as a function of bias voltage.

References


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