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Condensed Matter in Ultrafast and Superstrong Fields: Attosecond Phenomena

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We discuss latest developments in theory and recent experimental results for a new class of phenomena in condensed matter optics when a strong optical field $\sim$ 1-3 V/Å reversibly changes the solid within an optical cycle [1-7]. During a single-oscillation of a strong optical pulse, a dielectric undergoes a reversible transition to a semimetallic state, which follows the instantaneous optical field during time intervals on order of hundred attoseconds. Such a pulse drives ampere-scale currents in dielectrics and controls their properties, including optical absorption and reflection, extreme UV absorption, and generation of high harmonics [8] in a non-perturbative manner on a 100-as temporal scale. Applied to a metal, such a pulse causes an instantaneous and reversible loss of the metallic properties. We will also discuss or latest theoretical results on graphene, a semimetal, in a strong ultrashort pulse field [9, 10] revealing unique behavior inherent in graphene. These are fastest phenomena in optics unfolding within half period of light. They offer potential for petahertz-bandwidth signal processing, generation of high harmonics on a nanometer spatial scale, etc. **References** 1. M. Durach, A. Rusina, M. F. Kling, and M. I. Stockman, *Metallization of Nanofilms in Strong Adiabatic Electric Fields*, Phys. Rev. Lett. **105**, 086803-1-4 (2010). 2. M. Durach, A. Rusina, M. F. Kling, and M. I. Stockman, *Predicted Ultrafast Dynamic Metallization of Dielectric Nanofilms by Strong Single-Cycle Optical Fields*, Phys. Rev. Lett. **107**, 086602-1-5 (2011). 3. A. Schiffrin, T. Paasch-Colberg, N. Karpowicz, V. Apalkov, D. Gerster, S. Muhlbrandt, M. Korbman, J. Reichert, M. Schultze, S. Holzner, J. V. Barth, R. Kienberger, R. Ernstorfer, V. S. Yakovlev, M. I. Stockman, and F. Krausz, *Optical-Field-Induced Current in Dielectrics*, Nature **493**, 70-74 (2013). 4. M. Schultze, E. M. Bothschafter, A. Sommer, S. Holzner, W. Schweinberger, M. Fiess, M. Hofstetter, R. Kienberger, V. Apalkov, V. S. Yakovlev, M. I. Stockman, and F. Krausz, *Controlling Dielectrics with the Electric Field of Light*, Nature **493**, 75-78 (2013). 5. V. Apalkov and M. I. Stockman, *Metal Nanofilm in Strong Ultrafast Optical Fields*, Phys. Rev. B **88**, 245438-1-7 (2013). 6. V. Apalkov and M. I. Stockman, *Theory of Dielectric Nanofilms in Strong Ultrafast Optical Fields*, Phys. Rev. B **86**, 165118-1-13 (2012). 7. F. Krausz and M. I. Stockman, *Attosecond Metrology: From Electron Capture to Future Signal Processing*, Nat. Phot. **8**, 205-213 (2014). 8. T. Higuchi, M. I. Stockman, and P. Hommelhoff, *Strong-Field Perspective on High-Harmonic Radiation from Bulk Solids*, Phys. Rev. Lett. **113**, 213901-1-5 (2014). 9. H. K. Kelardeh, V. Apalkov, and M. I. Stockman, *Wannier-Stark States of Graphene in Strong Electric Field*, Phys. Rev. B **90**, 085313-1-11 (2014). 10. H. K. Kelardeh, V. Apalkov, and M. I. Stockman, *Graphene in Ultrafast and Superstrong Laser Fields*, Phys. Rev. B **91**, 045439-1-8 (2015).