Extreme light in nanostructured targets: shaping fields & particle flow

R.S. Marjoribanks[1], **L. Lecherbourg**[1], **J. Sipe**[1], **A. Héron**[2], **J.C. Adam**[2],
P. Audebert[3], **T. Preston**[4], **S. Vinko**[4], **and J.S. Wark**[4]
[1] Department of Physics, University of Toronto, 60 Saint George St., Toronto, ON M5S-1A7, Canada
[2] CPhT Ecole Polytechnique, 91128 Palaiseau Cedex, France
[3] LULI Ecole Polytechnique, 91128 Palaiseau Cedex, France
[4] Clarendon Laboratory, University of Oxford, Parks Road, Oxford, OX1 3PU, UK
Corresponding author: marj@physics.utoronto.ca

Abstract

In high-intensity laser-matter interaction with solids, absorption is simply generic to plasma; much of the laser energy is simply reflected, some is absorbed around critical density, and heating of bulk material depends on electron or x-ray transport. One escape is to use metal nanowires, which manipulate the wavelength-scale interface of targets to 'engineer' the dielectric function in the manner of a metamaterial, and permit ultra-intense light to propagate many microns through material that has an average density many times overdense. Our recent theoretical and experimental results for very high contrast relativistic pulses are presented.

Introduction

Absorption in ultra-intense laser-matter interaction is fundamentally nonlinear, but once all matter is ionized, for intensities above $\sim 1\times10^{12}$ W/cm^2, the Fresnel reflectivity is nearly always quite large. Nanostructured targets effectively suppress the material-field response required for a specularly reflected field, thus creating materials with high absorption even at ultra-high intensities.

Around 2000, we introduced [1] the use of nanowires as laser-plasma targets, with the aim to exploit a large low-intensity absorption (~95%). This material consists of a surface of end-standing 20–200nm diameter metallic fibers, in a structure resembling velvet fabric, cheaply fabricated by electrochemical means from a range of different atomic elements from aluminum to platinum [2]. These targets can produce x-rays up to 50x more efficiently [1], and exciting recent experiments have indicated energy-densities as high as 2 GJ cm^{-3} may be produced [3].

Modelling and Experiments

We'll present analytic results of small-signal linear modelling, in which the metallic nanowires are treated in an effective- medium approach. The anisotropy of the polarization response leads to different polarizability and conductivity for E-field directions along the wires and transverse to them. Using an isotropic tensor for the effective dielectric function, the net absorption can be found self-consistently as for a multilayer coating.

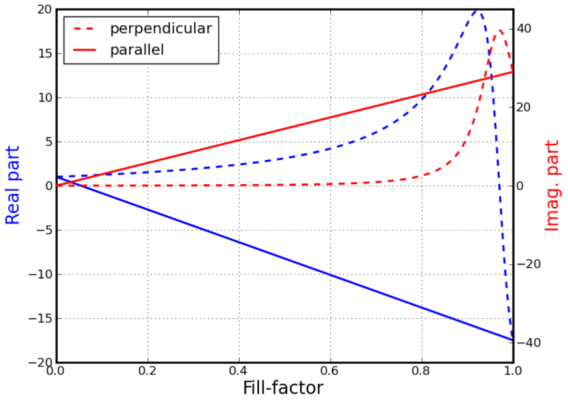

Fig. 1: Optical properties of nanowires are governed by their anisotropic dielectric function. Up to a fill-factor of 0.6x solid, the light component propagating straight into the material sees relatively little absorption.

At high intensities, we have simulated the interaction using a 2D particle-in-cell (PIC) code (EMI2D). We see the hydrodynamic timescale for the explosion of the nanowires to homogenize is considerably longer than 100fs pulse durations. At relativistic intensities, however, we see that the extraction of Brunel electrons leads to an electron plasma between wires, which abruptly changes the target reflectivity.

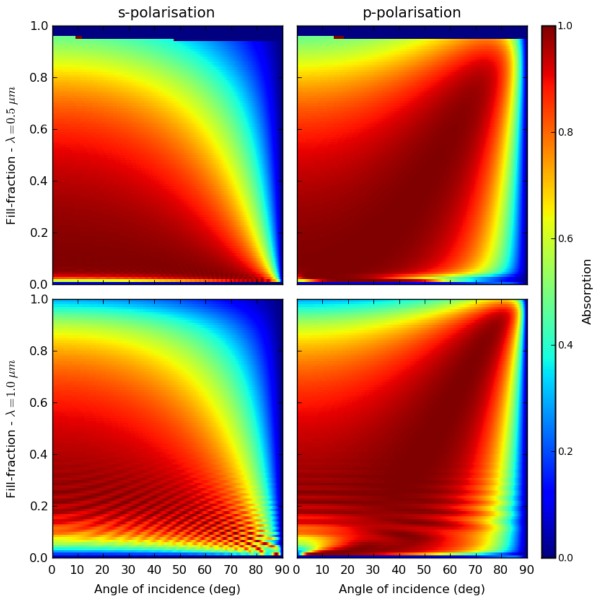

Fig. 2: Absorption of a 10μm-thick nanowire layer as a function of wavelength, incident polarization, angle of incidence and fill-fraction.

We'll present results of experiments using the Advanced Laser Light Source (ALLS) facility, 35fs pulses at λ = 800 nm, and pulse energies to 350 mJ.

References

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