Periodic multilayers and FEL radiation

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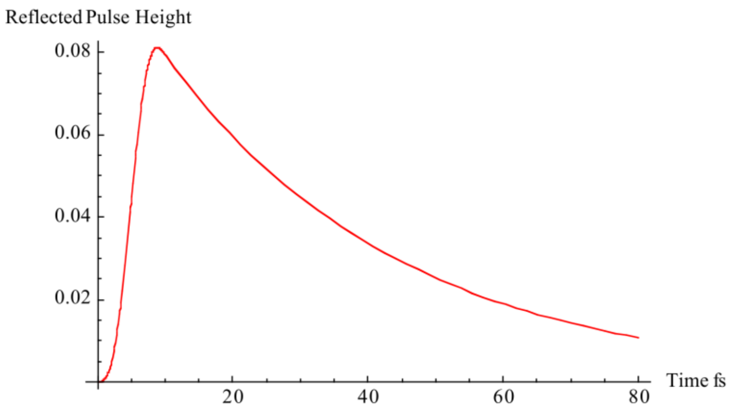
A few x-ray free electron laser (FEL) facilities are now in operation around the world. They produce very intense and very short pulses in the extreme ultra-violet, soft and hard x-ray ranges. However, FEL are not widely used to study the solid state and interaction with a periodic multilayer is generally only considered regarding the damaging effect. This is the aim of this communication to present simulations for periodic multilayers, designed as x-ray components, dealing with the short time and of the high intensity of a FEL pulse.

The time-dependence of the Bragg diffraction by a multilayer of nanometer period and its influence on the short pulse reflection are calculated in the framework of the coupled-wave theory. It appears that the indicial response presents a time-delay effect with a transient time conditioned by the extinction length. A numerical simulation is presented for a Bragg mirror in the x-ray range and a pulse of a sine-squared shape. In the presented example of a Fe/C multilayer illuminated by a 10 fs FEL pulse, Figure 1, the reflectance reaches the maximum value of 0.08 while in the steady state (continuous irradiation) it is 0.64.

We also propose to take advantage of the high intensity of the FEL pulses to make a distributed feedback laser. The idea is to implement a periodic multilayer acting as Bragg resonator acting both as the cavity necessary for the feedback and the active laser medium as one piece. The stimulated emission will be seeded by the spontaneous characteristic emission from one of the element of the periodic stack. We propose to use a Bragg resonator formed by a stack of Mg/SiC bilayers. The stimulated intensity of the Mg $L_{2,3}$ characteristic emission at 49 eV should be observed in a direction given by the Bragg angle, the angle satisfying the Bragg law for the Mg L emission and the considered period of the multilayer. We show, figure 2, based on an extended coupled-wave theory, that it would be possible to obtain a threshold gain compatible with the pumping provided by available X-FEL facilities.



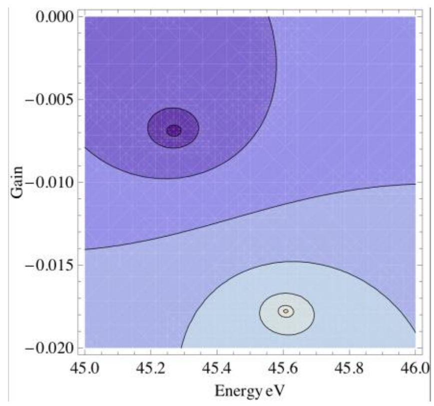


Figure 1 (left): Time dependence of the reflected pulse height with a sine-squared incident pulse of 8.05 keV energy and 10 fs width for the [Fe(2.5nm)/C(2.5nm]x100 multilayer.

Figure 2 (right): Reflectance of a Mg/SiC multilayer as a function of the photon energy and the net gain in the Mg layers. A lasing condition is found near the first Bragg region at E = 45.61 eV with a net gain of 17.8×10^{-3}, that is a gain value of 78600 cm^{-1}.