Photoionization Based Atomic Inner-Shell X-Ray Laser in Neon at 850 eV Realized at the Linac Coherent Light Source

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Since the invention of the laser fifty years ago, laser amplification of atomic transitions have been extended to increasingly high power and shorter wavelength. The photoionization inner-shell x-ray lasing scheme was first proposed in 1967 [1], but due to the requirement of an extremely fast and intense x-ray pump, has not been realized so far. Since then a broad variety of pump sources and gain media have been proposed, including optical-laser pumped plasma sources [2,3], synchrotrons [4], and VUV and x-ray free-electron lasers [5-7]. A K-shell neon laser pumped by a laser-created plasma was proposed in 1992 [2]. More recently, the pumping of several K-shell neon transitions by the Linac Coherent Light Source (LCLS) was analyzed [7]. We now report on the first demonstration of a photoionization based atomic inner shell x-ray laser in atomic Neon at 850 eV using the first operating X-ray free-electron laser, the LCLS at SLAC.

The figure shows a typical raw-image of the spectrum as detected on the CCD camera (linear scale). The vertical direction of the CCD is along the entrance slit of the spectrograph, the dispersive direction is along the horizontal. The transmitted LCLS corresponds to the line on the right at 960 eV and has a width of ~20 eV. The LCLS is based on self-amplified spontaneous emission and the spectrum is fluctuating and varies on a shot-to-shot basis. The atomic x-ray laser line has a well-reproducible spectrum, with an instrument-limited width of 2 eV (line on the left at 850 eV). Parameters of the LCLS: pulse energy 1.3 mJ, pulse duration 80 fs.

LCLS delivers x-ray pulses containing up to $10^{13}$ photons in 80 fs, of photon energies ranging from 0.5 to 8 keV. By focusing LCLS pulses into a dense neon gas sample to a micrometer-sized spot, a long narrow plasma column is produced on a fs time scale by photoionization of a K-shell electron. Thereby, a population inversion of the 2p-1s transition (850 eV) in singly ionized neon is established, lasting for only 2.7 fs due to the subsequent Auger decay of the created core hole. Fluorescence photons emitted at the front end of the plasma column get amplified by stimulated emission, resulting in ultra bright, high-intensity x-ray pulses at 850 eV photon energy of fs duration at the exit of the plasma column. The maximum energy in the Ne K-α line was estimated to be ~0.5 μJ resulting in ~4×10^9 photons. Increasing the LCLS pulse energy by a factor of 2, resulted in an increase of the Ne K-α signal by 4 orders of magnitude. With this experiment, a first step in the virtually unexplored field of non-linear quantum optics in the x-ray regime is made, which will potentially open a pathway to novel, non-linear spectroscopic x-ray techniques at new x-ray free electron laser sources.

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