Registration of 14.4 keV ^{57}Fe nuclear state excitation induced with the help of plasma created by the powerful femtosecond laser pulse

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Plasma created by high-power femtosecond laser pulse is well-known source of energetic electrons, ions and x-ray. Even at the moderate intensities energy of these products is high enough to excite a low-energy nuclear level. In this paper we report on first experimental prove of internal conversion decay of 14.41 keV isomeric level of ^{57}Fe excited by plasma corpuscular emission.

Experimental setup consists of Ti:Sapphire laser system (50 fs, 2 mJ) and vacuum chamber with two Fe-targets and electrostatic semi-cylindrical analyzer. Laser pulse was focused onto the 1st target (I • 10•˜ W/cm•) to create plasma. Plasma-accelerated ions (Fe^{1+}, Fe^{2+}, Fe^{3+} and H^+) with energy up to 100 keV bombarded the 2nd iron target. Electrons emitted from the surface of this target were detected by the analyzer. We varied the voltage and polarity between its concentric plates to change the energy and charge of detected particles with 10% resolution.

For each energy of the detected electrons results from more than 5000 laser shots were accumulated. Typical "current" obtained at the fixed electron energy of 12,0 ± 0,6 keV is plotted in the Fig.1.

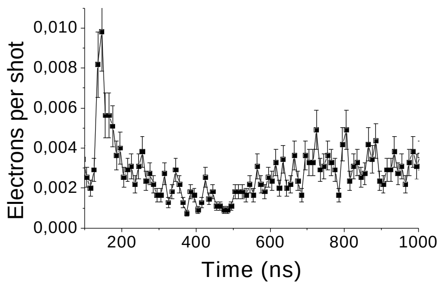

Fig. 1. Current for 12,0 ± 0,6 keV detected electrons

Sharp maximum delayed by 130 ns from instant of plasma creation exists for all energies of detected electrons. This delay corresponds well to the time-of-flight for protons with energy of 26 keV, which in its turn being mean energy of plasma accelerated protons estimated from independent ionic and x-ray measurements. Note that time-of-flight for 12-16 keV electron from the primary to the secondary target as well as from secondary target to the detector is less than 5 ns.

In Fig.2 we showed the spectra of the detected electrons. It has 2 parts: the smooth background and the peak. The first part is the result of near to full energy transfer from protons to electrons due to impact ionization. The sharp peak can't be interpreted in the context of purely atomic processes. Indeed, it's a result of a resonant process, but the maximum bounding energy of electrons in Fe atom is 7,2 keV (K-shell) so the atomic structure can't impact to production of such energetic electrons. We suppose that the excitation of ^{57}Fe ground nuclear level to 14.41 keV isomeric state and its subsequent conversional decay is the key for understanding of this puzzle.

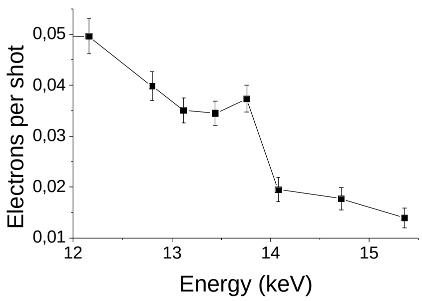

Fig. 2. Energy spectra in 110-170 ns after plasma creation

^{57}Fe, which is the main part of the 2nd target (98%), has the low-energy nuclear state at 14,4 keV. The main way of its relaxation is the internal conversional decay, when excitation energy is transferred to the inner-shell electrons. The products of this type of relaxation are electrons with energies equal to difference between nuclear excitation energy and bound energy of electrons. For the L-shell electrons (bounding energy – 0,8 keV) this difference is 14,4-0,8=13,6 keV.

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