Summary of the Multiphoton and Quantum Optics Groups

B. Adams

Nonlinear optics and multiphoton phenomena in the x-ray regime are a largely unexplored territory. Only very few experiments are feasible at present day 3rd generation x-ray sources. Among these are frequency mixing of optical laser light with x-rays and parametric down conversion of x-ray photons [1, 2, 3].

Possible applications of multiphoton/nonlinear optical phenomena which were discussed in the meeting are:

Mixing of optical laser light with x-rays: The mixing of optical light with x-rays has been demonstrated by Namikawa. In it, an optical photon and an x-ray photon combine to one under the restraint of energy and momentum conservation. Although the event rates for these processes are not well known, it is to be expected that they can be fairly large with high power optical lasers, judging from experience with the generation of high harmonics in the soft x-ray range from optical laser pulses. A possible application is to impose a precise energy shift on x-ray photons, for example the output of a nuclear Mössbauer monochromator. This could also be done with two optical lasers to shift the x-ray energy by the difference of the optical frequencies.

Stimulated Brillouin scattering: In materials research, static structures are the domain of 1st to 3rd generation x-ray sources. The study of dynamics became barely possible with 3rd generation sources and will become an important field at the 4th generation. Stimulated Brillouin scattering, a process in which phonons mediate the interaction of photons, is one way of probing the dynamics of a sample.

Improved depth resolution in microscopy: Nonlinear processes such as higher harmonic generation depend strongly on the intensity. By proper choice of the incident intensity, nonlinear processes such as higher harmonic generation occur only in the focal spot of an x-ray lens but not above or below (as seen along the beam). Thus, the information depth can be selected by choice of the focal depth.

Use of pairs of correlated photons, such as the ones generated in the process of parametric down conversion as a research tool. Possible applications include:

Sub-Poisson statistics in absorption spectroscopy: One of the two photons of a pair generated by parametric down conversion can be used as a reference while the other one hits the sample. By this scheme, the number of photons incident on the sample is known exactly and not only within Poisson statistics. Especially in the analysis of trace elements, this will lead to a drastic reduction of sample radiation exposure (see talk by B. Adams in this workshop).

2 photon interferometry: The coincidence contrast pattern depends on the difference in propagation phase of the two photons. If the two photons traverse the same path through the sample, this interference pattern is sensitive only to the differential properties of the two photons, such as energy difference or different polarization states (see talk by B. Adams in this workshop).

Imaging: The two photons from a parametric down conversion process have spatial correlations [4] which can be used for imaging of an absorptive sample Because the place where an absorption process is indicated by the other photon, the detector at the sample need not have spatial resolution and can be optimized for another property, such as energy resolution.

Study of quantum effects such as Bell's inequality, also known as the Einstein-Podolsky-Rosen paradox of quantum theory. These experiments are being performed by use of optical photon pairs from parametric down conversion. A serious obstacle for these experiments is the limited quantum efficiency of available detectors, at best barely reaching the theoretical minimum requirement of 71%. With x-ray detectors, almost 100% quantum efficiency are possible, making all experiments which probe the quantum nature of light much more precise than presently achievable.

Optical laser induced density modulations in a gas or atomic beam as an indestructible optical element for an x-ray FEL. Bragg reflection of optical laser light from a lattice of atoms which were bound by optical laser light has already been demonstrated [5]. The same principle could be used as a Bragg mirror for x-rays [6]. Not being made of solid matter, it would be indestructible by the FEL radiation. Reflectivities up to about 10^{-5} can be expected with present day technology. Such an element could be used to give the output of an FEL to several users who do not require the highest possible power.

An x-ray detector with fs time resolution: This detector works for x-rays of an energy which corresponds to a transition from an inner shell level to the valence band of a semiconductor. Because the valence band is completely filled, absorption by this transition is normally impossible. A high power femtosecond laser can depopulate the valence band for a short time window initiated by the femtosecond laser pulse and lasting as long as recombination takes place (typically less than a picosecond). This absorption process can in turn be detected by x-ray fluorescence.

A general observation was that not much is known about cross sections for nonlinear optical effects in the x-ray regime, both on the theoretical and on the experimental side. Because nonlinear processes are bound to play a role in experiments with an x-ray FEL, it is imperative to work on the theoretical and, as far as possible, on the experimental side of this field.

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