0.3, 0.6, 0.9, 1.5, and 2.1 m from the target.

These experiments reveal the following properties of the radiation.

a) The brightest part of the radiation to be referred to as the "hot spot" radiation propagates in forward direction along the axis of the Van de Graaff inclined at an angle of 15′ of arc, that is 4.4 mrad with respect to the smooth surface of the target. For a cylindrical bore, the "hot spot" appears circular having greater intensity at the periphery of the circle. If the inner surface is highly polished the "hot spot" appears as a "hot ring."

b) The background radiation surrounding the "hot spot" is also circular in shape. The angle subtended by the "larger hot spot" at the center of the collimator is about 1° but according to the X-ray optical geometry the subtended angle should have been 8°.

c) The intensity of the "hot spot radiation" is independent of Z and the electrical conductivity of the material.

2) A Harshaw Type 6S4/2 detector with 1½ in thick and 1½ in diameter of NaI(Tl) crystal was placed at a distance of 1.52 m from the target. A ¼ in thick lead or aluminum is placed in between the detector and the target to improve the signal-to-noise background of the radiation. A Tullamore model ST800DM 800-channel pulse height analyzer was used to obtain the spectra. The calibration curve was a superposition of Cs^{137} and Co^{57}.

The observed peaks are independent of the energy of the incident electron beam so long as it is higher than the required values for characteristic peaks.

3) A rod of aluminum 76.2 mm long and 3.175 mm diameter was placed in the path of the "hot spot" radiation bathing the surface of the rod. It is most interesting to note that the rod resumes the emission characteristics of the original target radiation and a very bright "hot spot" is obtained exactly at the calculated distance of convergent beam from the end of the rod again making an angle of 15 min of arc with the surface.

Similar experiments imposing an aluminum plate in the path of the "hot spot" radiation reveal a sharp line at the calculated distance from the plate. These experiments very clearly reveal highly directional scattering from secondary objects.

4) A number of mass absorption coefficient experiments using lead of known thicknesses clearly reveal that there exists a mechanism causing large transmission coefficients. The different sets of experiments reveal 2–10 times the value transmission coefficient for lead.

We have developed a phenomenological kinematical theory to ensure the conservation of momentum and energy through a successive alternate sequence of bremsstrahlung associated with the collapse of an aligned dipole normal to the surface and a photoelectric process transferring the photon's energy to the electrons at the zone boundary. The plausible theory presented is based on the concept of parametric coupling of electromagnetic waves at the bremsstrahlung limit λ_ν with the de Broglie electron waves λ_e by the coupling equation $n\lambda_e = \lambda_\nu$, where n is any integer greater than 1. The predicted discrete energy values of photons are 360, 127, 68, 42, and 29 keV for $n = 2, 3, 4, 5$, and 6, respectively. The predicted values agree well with the experimental results.

P.4A Distributed Feedback X-Ray Lasers in Single Crystals, Amnon Yariv and Avraham Gover, *California Institute of Technology, Pasadena, Calif. 91109.*

There are two main obstacles in the way of obtaining laser action in the X-ray region. The first involves the pumping necessary to obtain the critical inversion. The second one is that of the optical feedback.

Estimates of the losses associated with potential X-ray media show that superradiant laser action is not very likely in the $1\ \text{Å} \lessapprox \lambda \lessapprox 10\ \text{Å}$ region and that efficient low-loss feedback will be necessary to obtain laser action.

In this talk we will consider the problem of propagation of an X-ray laser beam inside a crystal lattice. We take the dielectric constant $\epsilon(\bar{r})$ as a periodic function with symmetry properties identical to that of the crystal group and calculate the Fourier coefficients $a_{\bar{G}}$ in

$$(\bar{r}) = \sum_{G} a_{\bar{G}} e^{i\bar{G}\cdot\bar{r}}$$

where $\bar{G}$ is the reciprocal lattice vector. We find that in certain classes of crystals Bragg reflection from the $\langle 111\rangle$ to the $\langle\bar{1}\bar{1}\bar{1}\rangle$ direction provides an intense feedback for a beam with a wavelength λ such that

$$d_{111} = \frac{\lambda}{2} \qquad (1)$$

where d_{111} is the atomic planar spacing along the $\langle 111\rangle$ direction.

An electromagnetic analysis of the propagation problem is combined with Kogelnik and Shank's distributed feedback analysis[1] to obtain the laser threshold gain.

The possibility of crystals which, in addition to satisfying the feedback condition (1), have a K_α transition at λ is examined. We find that such crystals exist so that under the proper pumping conditions both amplification and feedback are possible in a single crystal with no external mirrors.

[1]H. Kogelnik and C. V. Shank, *J. Appl. Phys.*, vol. 43, p. 2327, 1972.

P.4B On the Possibility of a Distributed Feedback X-Ray Laser,* Robert A. Fisher,† *Department of Applied Science, Davis-Livermore and Lawrence Livermore Laboratory, University of California, Livermore, Calif. 94550.*

Although a number of X-ray laser resonators have been proposed,[1] they all have cavity transit times which far exceed the typical X-ray fluorescence lifetimes. To implement the X-ray laser scheme[2] in which the sample is to be pumped by a fast-rising (10^{14} s) pulse of X-rays, we suggest a distributed feedback design which incorporates the cavity and the active medium as one piece. This scheme has been successful for visible dye lasers.[3] X-ray distributed feedback can be achieved by choosing a crystal with the appropriate periodic lattice spacing for backward Bragg scattering at the characteristic emission frequency of one of its constituents. This device has a far shorter cavity transit time, and it eliminates problems associated with the alignment of multiple elements. Since a number of experimental efforts are now under way,[4] we suggest an additional criterion for selecting potential samples. With this distributed feedback, the required pumping power could be reduced and, thus, X-ray laser action could possibly be achieved at an earlier date.

Many emitting species can be considered. In the case of oxygen, the K_α wavelength is $\sim 23\frac{1}{2}$ Å. Numerous crystals have been found with approximately the appropriate spacing. A cubic millimeter would be more than sufficient, and the crystal would be destroyed in a single shot. For silicon, a good candidate is β-cristobalite[5] (SiO_2); its K_α emission and periodic spacing differ by only one part in 10^3.

In the scheme presented here, the electron density distribution must remain periodic while inversion is established. We can estimate the "melting time" of a pumped crystal by the following argument. We assume that the singly ionized ion satisfies the one-dimensional equation $\frac{1}{2}MV^2 =$

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[1]B. Okkerse, *Phillips Res. Rep.*, vol. 18, p. 413, 1963; W. L. Bond, M. A. Duguay, and P. M. Rentzepis, *Appl. Phys. Lett.*, vol. 10, p. 216, 1967; R. D. Deslattes, *Appl. Phys. Lett.*, vol. 12, p. 133, 1968; R. M. T. Cotterill, *Appl. Phys. Lett.*, vol. 12, p. 403, 1978; A. V. Kolpakov, R. W. Kuz'min, and V. M. Rayboy, *J. Appl. Phys.*, vol. 41, p. 3549, 1970.

[2]M. A. Duguay and P. M. Rentzepis, *Appl. Phys. Lett.*, vol. 10, p. 350, 1967; M. A. Duguay, in *Laser Focus*, p. 41, Nov. 1973.

[3]H. Kogelnik and C. V. Shank, *Appl. Phys. Lett.*, vol. 18, p. 152, 1971.

[4]A list of some present experimental efforts has been prepared by M. A. Duguay and R. A. Andrews in *Laser Focus*, pp. 42–46, Nov. 1973.

[5]*Handbook of Chemistry and Physics*, R. C. Weast, Ed. (The Chemical Rubber Company, Cleveland, Ohio, 1970). 51st ed., p. B-210.