CLAIMS

1. A method of generating X-ray emission, comprising the steps of:

generating a beam of free electrons using an electron source;

directing the beam of free electrons onto a crystalline material having a periodic material structure;

generating X-ray emission as a result of the interaction between the free electrons and the crystalline material; and

extracting a portion of the X-ray emission for providing an X-ray beam having a selected photon energy;

wherein the selected photon energy is tunable, at least, by changing an azimuthal collection angle of the extracted portion of the X-ray emission about an axis parallel to the beam of free electrons, and/or by rotating the crystalline material azimuthally about the axis parallel to the beam of free electrons.

2. The method of claim 1, further comprising tuning the selected photon energy by controlling one or more of a group consisting of a collection angle for extracting the X-ray beam relative to the beam of free electrons, the crystalline material and its atomic composition, and an energy of the beam of free electrons.

3. The method of claim 2, comprising tuning the selected photon energy by simultaneously controlling at least two of a group consisting of the tilt angle of the crystalline material relative to the beam of free electrons, the collection angle for extracting the X-ray beam relative to the beam of free electrons, the crystalline material and its atomic composition, and the energy of the beam of free electrons.

4. The method of any one of the preceding claims, wherein the tilt angle is controllable in a range from a channelling configuration in which the periodic structure extends substantially parallel to the beam of free electrons and a perpendicular configuration in which the period structure extends substantially perpendicular to the beam of free electrons.

5. The method of any one of the preceding claims, comprising directing the beam of free electrons onto a stack of two or more crystalline materials with different periodic structures and extracting two or more X-rays beams of different energy from respective ones of the two or more crystalline materials.

6. The method of any one of the preceding claims, wherein extracting the X-ray beam comprises disposing one or more windows having respective selected dimensions and collection angle at respective selected distances from the crystalline material such that only the X-ray beams passing through the respective one or more windows are extracted while a remaining portion of the generated X-ray emission is blocked.

7. The method of claim 6, further comprising controlling the dimensions of the respective one or more windows by changing apertures of the respective one or more windows.

8. The method of any one of the preceding claims, wherein the selected energy of the extracted X-ray beam or beams is controlled based on consideration of quantum recoil in the interaction between the free electrons and the crystalline material or materials.

9. The method of claim 8, wherein the selected energy of the extracted X-ray beam or beams is controlled based on:

$$E_p = -\frac{2\hbar g_z v_0 + \hbar^2 c^2 g^2 / E_i}{1 - n v_0 \cos(\theta_{\text{obs}})/c - n\hbar c \boldsymbol{g} \cdot \widehat{\boldsymbol{q}}/E_i}$$

$$\times \left[1 + \sqrt{1 - \frac{n^2 - 1}{n^2} \frac{\hbar^2 c^2 g^2 + 2\hbar E_i g_z v_0}{[E_i (v_0 \cos\theta_{\text{obs}}/c - 1/n + \hbar c \boldsymbol{g} \cdot \widehat{\boldsymbol{q}}]^2)}}\right]^{-1},$$

where E_i is the initial total energy (i.e., including rest mass) of the incident electron, $\widehat{\boldsymbol{q}} = (\sin\theta_{\text{obs}} \cos\phi_{\text{obs}}, \sin\theta_{\text{obs}} \sin\phi_{\text{obs}}, \cos\theta_{\text{obs}})$ is the unit vector of the emitted photon wave vector $\boldsymbol{q}$, and ϕ_{obs} is the azimuthal angle of $\boldsymbol{q}$.

10. The method of claim 9, wherein, according to the Lorentz oscillator model, the refractive index in the X-ray range is given by $n = 1 - \omega_p^2/2\omega^2 \approx 1$, where ω_p is the plasma frequency and ω is the angular frequency of the X-rays, and the selected energy of the extracted X-ray beam or beams is determined based on:

$$E_p \approx -\frac{\hbar g_z v_0 + \hbar^2 c^2 g^2 / 2E_i}{1 - n v_0 \cos(\theta_{\text{obs}})/c - n\hbar c \boldsymbol{g} \cdot \widehat{\boldsymbol{q}}/E_i},$$

11. A system for generating X-ray emission, comprising:

an electron source disposed in a vacuum chamber for generating a beam of free electrons;

an electron optics disposed in the vacuum chamber for directing the beam of free electrons onto a crystalline material disposed in the vacuum chamber and having a periodic material structure, whereby X-ray emission is generated as a result of the interaction between the free electrons and the crystalline material; and

one or more windows in a wall structure of the vacuum chamber for extracting a portion of the X-ray emission for providing an X-ray beam having a selected photon energy, the one or more windows having respective selected dimensions and collection angles at respective selected distances from the crystalline material such that only the X-ray beams passing through the respective one or more windows are extracted while a remaining portion of the generated X-ray emission is blocked;

wherein the selected photon energy is tunable, at least, by changing an azimuthal collection angle of the extracted portion of the X-ray emission about an axis parallel to the beam of free

electrons, and/or by rotating the crystalline material azimuthally about the axis parallel to the beam of free electrons.

12. The system of claim 11, wherein the selected photon energy is further tunable by controlling one or more of a group consisting of a collection angle for extracting the X-ray beam relative to the beam of free electrons, the crystalline material and its atomic composition, and an energy of the beam of free electrons.

13. The system of claim 12, wherein the selected photon energy is tunable by simultaneously controlling at least two of a group consisting of the tilt angle of the crystalline material relative to the beam of free electrons, the collection angle for extracting the X-ray beam relative to the beam of free electrons, the crystalline material and its atomic composition, and the energy of the beam of free electrons.

14. The system of any one of claims 11 to 13, wherein the tilt angle is controllable in a range from a channelling configuration in which the periodic structure extends substantially parallel to the beam of free electrons and a perpendicular configuration in which the period structure extends substantially perpendicular to the beam of free electrons.

15. The system of any one of claims 11 to 14, comprising a stack of two or more crystalline materials with different periodic structures and wherein the windows in the wall structure of the vacuum chamber are disposed for extracting two or more X-rays beams of different energy from respective ones of the two or more crystalline materials as a result of the interaction between the free electrons and the two or more crystalline materials.

16. The system of any one of claims 11 to 15, wherein the dimensions of the respective one or more windows are controllable by changing apertures of the respective one or more windows.

17. The system of any one of claims 11 to 16, wherein the selected energy of the extracted X-ray beam or beams is controlled based on consideration of quantum recoil in the interaction between the free electrons and the crystalline material or materials.

18. The system of claim 17, wherein the selected energy of the extracted X-ray beam or beams is controlled based on:

$$E_p = -\frac{2\hbar g_z v_0 + \hbar^2 c^2 g^2 / E_i}{1 - n v_0 \cos(\theta_{\text{obs}})/c - n\hbar c \boldsymbol{g} \cdot \hat{\boldsymbol{q}}/E_i}$$

$$\times \left[1 + \sqrt{1 - \frac{n^2 - 1}{n^2} \frac{\hbar^2 c^2 g^2 + 2\hbar E_i g_z v_0}{[E_i (v_0 \cos\theta_{\text{obs}}/c - 1/n + \hbar c \boldsymbol{g} \cdot \hat{\boldsymbol{q}}]^2)}}\right]^{-1},$$

where E_i is the initial total energy (i.e., including rest mass) of the incident electron, $\hat{\boldsymbol{q}} = (\sin\theta_{\text{obs}} \cos\phi_{\text{obs}}, \sin\theta_{\text{obs}} \sin\phi_{\text{obs}}, \cos\theta_{\text{obs}})$is the unit vector of the emitted photon wave vector $\boldsymbol{q}$, and ϕ_{obs} is the azimuthal angle of $\boldsymbol{q}$.

19. The system of claim 18, wherein, according to the Lorentz oscillator model, the refractive index in the X-ray range is given by $n = 1 - \omega_p^2/2\omega^2 \approx 1$, where ω_p is the plasma frequency and ω is the angular frequency of the X-rays, and the selected energy of the extracted X-ray beam or beams is determined based on:

$$E_p \approx -\frac{\hbar g_z v_0 + \hbar^2 c^2 g^2/2E_i}{1 - n v_0 \cos(\theta_{\text{obs}})/c - n\hbar c \boldsymbol{g} \cdot \widehat{\boldsymbol{q}}/E_i},$$

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