The magnetron free electron laser

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July 17, 2015

Abstract

We determine the power spectrum generated by the system of N electrons moving coherently in the electromagnetic field of the planar magnetron. We argue that for large N and high intensity of electric field, the power of radiation of such magnetron laser, can be sufficient for application in the physical, chemical, biological and medicine sciences. In medicine, the magnetronic laser, can be used for the therapy of the localized cancer tumors. The application such new electron laser as the photoelectron spectroscopy facility in the solid state physics and chemistry is evident.

1 Introduction

Any of devices that produces an intensive beam of light not only of a very pure single color but all colors is a laser. While the gas lasers and masers produce practically a single color, the so called lasers on the free electrons such as undulators and wigglers produce all spectrum of colors. These spectra are generated in the form of so called synchrotron radiation because they are generated during the motion of electron when moving in the magnetic field.

The electrons moving inside the planar magnetron field evidently produce also the synchrotron radiation because planar magnetron is a system of two metal charged plates immersed into homogenous magnetic field which is perpendicular to the homogenous electric field between plates. The planar magnetron producing photons has the same function as the free electron laser such as wiggler or undulator. So, we denote such device by word magnetron free electron laser, or shortly MAGFEL. The motion of electrons is determined by the equation of motion following from electrodynamics of charges in homogenous electric and magnetic field. The produced energy of electrons is given by the Larmor formula.

Although the radiation of one electron from one trajectory is very weak, the total radiation of a MAGFEL is not weak because the process of radiation can be realized by many electrons moving along the same trajectory. There is no problem for today technology to construct MAGFEL of high intensity electric and magnetic fields.

2 The nonrelativistic motion of an electron in the field of the planar magnetron

We shall identify the direction of magnetic field $\mathbf{H}$ with z-axis and he direction of electric field $\mathbf{E}$ is along the y-axis. The nonrelativistic equation of motion of an electron is as follows [1]:

$$m\dot{\mathbf{v}} = e\mathbf{E} + \frac{e}{c}(\mathbf{v}\times\mathbf{H}). \tag{1}$$

This equation can be rewritten in the separate coordinates as follows (we do not write the z coordinate):

$$m\ddot{x} = \frac{e}{c}\dot{y}H, \tag{2}$$

$$m\ddot{y} = eE_y - \frac{e}{c}\dot{x}H. \tag{3}$$

Integrating eqs (2), (3) and choosing the constant of integration so that at $t = 0, x = y = 0$, we obtain

$$x = \frac{a}{\omega_0}\sin\omega_0 t + \frac{cE_y}{H}t, \quad y = \frac{a}{\omega_0}(\cos\omega_0 t - 1). \tag{4}$$

These equations define in a parametric form a trochoid. Depending on whether a is larger or smaller in absolute value than the quantity cE_y/H, the projection of the trajectory on the plane xy have different form.

If $a = -cE_y/H$, then, equation (4) becomes [1]:

$$x = \frac{cE_y}{\omega_0 H}(\omega_0 t - \sin\omega_0 t), \quad y = \frac{cE_y}{\omega_0 H}(1 - \cos\omega_0 t). \tag{5}$$

These equations are the parametric equation of cycloid in the plane xy. The cycloid can be formed also mechanically as a curve traced out by a point on the circumference of a circle that rolls without slipping along a straight line. Constant $R = cE_y/\omega_0 H$ is equal to the radius of the rolling circle. The distance from the point with parameter $t = 0$ to the point with parameter $t = 2\pi/\omega_0$ is $2\pi R$. The drift velocity is $R\omega_0$ and it is the velocity of the center of the circle.

The generalization to the relativistic situation can be performed using the approach of Landau et all. [1].

The aim of this article is to investigate the radiation of electron in case that the motion is just along cycloid, i. e. the trajectory of an electron in the planar magnetron. We want to show that such configuration of fields is an experimental device which can be used as the new effective source of synchrotron radiation.

For the sake of simplicity we calculate spectrum of radiation of MAGFEL in the system S' which moves with regard to the magnetron body at the drift velocity $v_{drift} = R\omega_0$. Then, all electron trajectories are circles and the radiation of this system is the synchrotron radiation. Then, we can transform the power spectrum to the system joined with the body of the planar magnetron. However, we shall see that the spectrum is modified slightly, because the drift velocity is not relativistic in our situation.

The motion of electrons differs form the motion of electrons in wigglers and undulators where the trajectories of electrons are not cycloids and the motion is highly relativistic.

It is also possible to realize the relativistic motion of electrons in MAGFEL. However, it needs special experimental conditions which are very expensive.

3 The kinematics of MAGFEL

The expression for the instantaneous power radiated by the nonrelativistic charge e undergoing an acceleration $\mathbf{a} = d\mathbf{v}/dt$ is given by the Larmor formula as follows [2]:

$$P = \frac{2}{3}\frac{e^2}{c^3}\left(\frac{d\mathbf{v}}{dt}\right)^2 = \frac{2}{3}\frac{e^2}{m^2c^3}\left(\frac{d\mathbf{p}}{dt}\right)^2. \tag{6}$$

So we see that only electrons with undergoing big acceleration can produce sufficient power of radiation of photons. If we consider electrons in the system S' with the drift velocity $v = v_{drift} = cE_y/H$, then the equations of the trajectory are as follows:

$$x = -\frac{cE_y}{\omega_0 H}\sin\omega_0 t, \quad y = \frac{cE_y}{\omega_0 H}(1 - \cos\omega_0 t). \tag{7}$$

They can be rewritten in the form:

$$x^2 + \left(y - \frac{cE_y}{\omega_0 H}\right)^2 = \left(\frac{cE_y}{\omega_0 H}\right)^2, \tag{8}$$

which is evidently an equation of a circle with the radius

$$R = \frac{cE_y}{\omega_0 H} = \left(\frac{eH}{mc}\right)^{-1}\frac{cE_y}{H} = \frac{mc^2E_y}{eH^2}. \tag{9}$$

The corresponding tangential velocity is

$$v_t = \sqrt{\dot{x}^2 + \dot{y}^2} = \frac{cE_y}{H} = v_{drift}. \tag{10}$$

The corresponding acceleration is

$$\sqrt{\ddot{x}^2 + \ddot{y}^2} = eE_y/m, \tag{11}$$

which corresponds to the Newton law, mass $\times$ acceleration $=$ force $= eE_y$, which agrees with the introducing the electrostatic intensity E_y inside the planar magnetron.

Big acceleration gives big radiation and also big tangential velocity for the given intensity of the magnetic field. However, big intensity of the magnetic field reduces the big circle to the small size.

If we describe the motion of electrons in planar magnetron in the SI system of units [2] and in the system S', then, we write the following equations of motion:

$$x = -\frac{E_y}{\omega_0 B}\sin\omega_0 t, \quad y = \frac{E_y}{\omega_0 B}(1 - \cos\omega_0 t), \tag{12}$$

where B is the magnetic induction and $\omega_0 = eB/m$.

Then, for the radius of a circle, we get

$$R = \frac{E_y}{\omega_0 B} = \left(\frac{eB}{m}\right)^{-1}\frac{E_y}{B} = \frac{mE_y}{eB^2}. \tag{13}$$

The corresponding tangential velocity is $v_t = \sqrt{\dot{x}^2 + \dot{y}^2} = E_y/B = v_{drift}$.

The planar magnetron is composed from the cathode and anode. If the cathode is cold, then after application the voltage the emission of electrons occurs accidentally from the arbitrary points of the cathode. In order to establish only one starting point of the emission of electrons, we connect cathode with the prismatical, or conical protrusion with the vertex between anode and cathode. Then, the electrons are sucked from the vertex to the anode and move along the trajectory of the constant geometrical form. Then, the planar magnetron as a source of synchrotron radiation works.

In case of the thermal cathode, the initial velocities of electrons are determined by the statistical law. The consequence of it is, that many different cycloids are generated and the coherence of motion is broken.

4 The spectrum of the radiation of coherently moving electrons

We shall derive the power spectrum formula of the synchrotron radiation generated by the motion of N electrons moving in the field of the planar magnetron. We can follow approach of Schwinger et al. [3] and [4, 5] but we will follow also the author articles [6, 7]. We write the spectral formula for one electron moving in vacuum:

$$P(\omega, t) = -\frac{\omega}{4\pi^2}\int d\mathbf{x}d\mathbf{x}'dt'\left[\frac{\sin\frac{\omega}{c}|\mathbf{x} - \mathbf{x}'|}{|\mathbf{x} - \mathbf{x}'|}\right] \times$$

$$\cos[\omega(t - t')][\varrho(\mathbf{x}, t)\varrho(\mathbf{x}', t') - \frac{1}{c^2}\mathbf{J}(\mathbf{x}, t)\cdot\mathbf{J}(\mathbf{x}', t')]. \tag{14}$$

We determine the power spectral formula in the system S' moving with the drift velocity $v_{drift} = cE_y/H$ with regard to the body of the magnetron. In this case motion of electron is not cycloid but the circle and we can repeat some formulas which were used in the previous work of author [6, 7]. Such approach is meaningful because we can return to the system S using the formulas relating frequencies and distribution in the system S with frequencies and photon distribution in the system S' [1].

We will apply the formula (14) to the N-body system with the same charged particles which moves along the same circles with diameters R with the centers at points 0, $2R$, $4R$, ..., $2(N-1)R$, where N is the natural number.

Now, we write for the charge density ϱ and for the current density $\mathbf{J}$ of the N-body system:

$$\varrho(\mathbf{x},t) = e\sum_{i=1}^{i=N}\delta(\mathbf{x}-\mathbf{x_i}(t)), \quad \mathbf{J}(\mathbf{x},t) = e\sum_{i=1}^{i=N}\mathbf{v}_i(t)\delta(\mathbf{x}-\mathbf{x_i}(t)), \tag{15}$$

where $\mathbf{x_i}(t)$ is the trajectory of electrons in MAGFEL. In order to be in the formal identity with the Schwinger approach, we perform elementary transformation of variables in eq. (12) which has no influence on the spectrum of emitted photons. In other words we make the following transitions:

$$S \to S'; \quad \omega_0 \to -\omega_0; \quad y \to y - R; \quad \omega_0 t \to \omega_0 t + \frac{\pi}{2}. \tag{16}$$

Then, we can write $\mathbf{x_i}(t)$ in eq. (15) in the form:

$$\mathbf{x}_i(t) = i\mathbf{a} + \mathbf{x}(t) = i\mathbf{a} + R(\mathbf{i}\cos(\omega_0 t) + \mathbf{j}\sin(\omega_0 t), \quad i = 1,2,3,...,N; \quad \mathbf{a} = (2R,0,0). \tag{17}$$

From the physical situation follows with ($H = |\mathbf{H}|, W =$ energy of a particle)

$$\mathbf{v}_i = d\mathbf{x}_i/dt = d\mathbf{x}/dt = \mathbf{v}(t), \quad \omega_0 = v/R, \quad R = \frac{\beta W}{eH}, \quad \beta = v/c, \quad v = |\mathbf{v}|. \tag{18}$$

After insertion of eqs. (17) and (18) into eq. (14), and after some mathematical operations we get

$$P(\omega',t) = -\frac{\omega'}{4\pi^2}\frac{\mu}{n^2}e^2\int_{-\infty}^{\infty}dt'\cos\omega'(t-t')\left[1-\frac{\mathbf{v}(t)\cdot\mathbf{v}(t')}{c^2}n^2\right]\sum_{i,j=1}^{N}\left\{\frac{\sin\frac{n\omega'}{c}|\mathbf{x}_i(t)-\mathbf{x}_j(t')|}{|\mathbf{x}_i(t)-\mathbf{x}_j(t')|}\right\}. \tag{19}$$

Using $t' = t + \tau$, we get with $\mathbf{x}(t) = R(\mathbf{i}\cos(\omega_0 t) + \mathbf{j}\sin(\omega_0 t)$:

$$\mathbf{x}_i(t) - \mathbf{x}_j(t') = (i-j)\mathbf{a} + \mathbf{x}(t) - \mathbf{x}(t+\tau) = (i-j)\mathbf{a} + \mathbf{A}, \tag{20}$$

where $\mathbf{A} \stackrel{d}{=} \mathbf{x}(t) - \mathbf{x}(t+\tau)$.

Using geometrical representation of vector $\mathbf{x}(t)$, we get:

$$|\mathbf{A}| = [R^2 + R^2 - 2RR\cos(\omega_0\tau)]^{1/2} = 2R\left|\sin\left(\frac{\omega_0\tau}{2}\right)\right|, \tag{21}$$

and

$$\mathbf{v}(t)\cdot\mathbf{v}(t+\tau) = \omega_0^2 R^2\cos\omega_0\tau. \tag{22}$$

The absolute values of the x differences are as follows:

$$|\mathbf{x}_i(t) - \mathbf{x}_j(t')| = \left((i-j)^2 a^2 + 2(i-j)\mathbf{a}\cdot\mathbf{A} + A^2\right)^{1/2}. \tag{23}$$

Now, using the definition of $\mathbf{a} \equiv (2R, 0, 0)$ and $|\mathbf{A}|$, we get

$$|\mathbf{x}_i(t) - \mathbf{x}_j(t')| = \left((i-j)^2 4R^2 + 8R^2(i-j)\cos\theta + 4R^2 \sin^2 \frac{\omega_0 \tau}{2}\right)^{1/2}, \tag{24}$$

where θ is an angle between $\mathbf{a}$ and $\mathbf{A}$.

Now, we are prepared to calculate the power spectrum formula for emission of photons by the planar magnetron with N electrons. We have all ingredients for determination of the final formula. However, we see that the last formula is very complicated and it means that the calculation of the power spectrum will be not easy. So, in such a situation, we can use some approximation. One possible approximation is to consider the contributions only of the terms with $i = j$. Then we get:

$$P_N \approx NP, \tag{25}$$

where $P(\omega')$ was expressed by Schwinger et al. [3] in the form

$$P(\omega') = \sum_{l=1}^{\infty} \delta(\omega' - l\omega_0) P_l, \tag{26}$$

where

$$P_l(\omega', t) = N \frac{e^2}{\pi} \frac{\omega' \omega_0}{v} \left(2\beta^2 J'_{2l}(2l\beta) - (1-\beta^2) \int_0^{2l\beta} dx J_{2l}(x)\right), \tag{27}$$

where N is the number of arcs forming the trajectory of electrons with one electron at one arc.

It is well known that for the low frequencies

$$P(\omega) \approx \omega^{(1/3)} \tag{28}$$

and for high frequencies the dependence of $P(\omega)$ is exponentially decreasing.

If we take the idea that the discrete spectrum parametrized by number l is effectively continuous for $l \gg 1$, then, in such a case there is an relation [5]:

$$P(\omega') = P_{(l=\omega'/\omega_0)} \left(\frac{1}{\omega_0}\right). \tag{29}$$

Formulas (27), (28), (29) concerns the situation with electrons moving along the circular trajectory. In other words, we work in the system which moves with regard to the body of magnetron at the drift velocity v_{drift}. In the case that we are in the system joined with the body of magnetron, all wave lengths are shifted to the blue edge because of the Doppler effect. If we consider only photons moving along the x-axis, then, we can use the formula for the Doppler shift of the following form [8]:

$$\lambda = \lambda' \sqrt{\frac{1-\beta}{1+\beta}}. \tag{30}$$

because we move toward the photon emission.

For the drift velocity $v_{drift} = E_y/B$, with the electric field 10^6 V/m and magnetic field 1T, we get $\lambda/\lambda' \approx 1 - \beta \approx 0.997$, for $\beta = 10^6/(3 \times 10^8) \approx 3.3 \times 10^{-3} \ll 1$. It represents practically no shift, because of the small drift velocity.

5 The technical parameters of MAGFEL

Let us determine acceleration of electron with the following parameters: $E_y = 10^6$ V m^{-1}, with $e = 1.6 \times 10^{-19}$C, and $m = m_e = 9.1 \times 10^{-31}$kg. We get $eE_y/m \approx 1.75 \times 10^{17}$m s^{-2}.

In the SI system the radiation power is as follows [9]:

$$P = \frac{e^2}{6\pi\varepsilon_0 c^3} \times \left(\frac{eE_y}{m}\right)^2, \tag{31}$$

where $\varepsilon_0 = 8.8 \times 10^{-12}$A s V^{-1} m^{-1}.

For $E_y = 10^6$ V m^{-1}, with $e = 1.6 \times 10^{-19}$ C, $c = 3 \times 10^8$ m s^{-1} and $m = m_e = 9.1 \times 10^{-31}$ kg, we get using the value of acceleration determined in equation (14): $P \approx 1.75 \times 10^{-20}$ W.

Of course, this is very small radiation, however this is only for one electron, or, in other words for one elementary charge. If we prepare regime with many charges, say $q = 10^{10}e$, then the situation will be substantially different. We obtain $P = 1.75$ W.

We can also easily determine the radius of circle in the system S'. The corresponding formula in the SI system of units is given by equation (13): $R = mE_y/eB^2$, where B is the magnetic induction. For $B = 1$T, we get: $R \approx 5.7 \times 10^{-6}$ m.

It follows from the last formula, that the radius of circle is very small and it means that the external observer sees the radiating "straight line", which is parallel with the x-axis. Every point of this "straight line" radiates, however the enhancement of radiation is only at the direction of "straight line".

If we are interested also in the value of the drift velocity for our parameters of the MAGFEL, then we get: $v_{drift} = E/B = 10^6$ m s^{-1}.

So we see, that we have chosen the parameters in a such way that the drift velocity is substantially smaller than the velocity of light.

The quantity ω_0 in the situation with $B = 1$T is determined as follows: $\omega_0 = eB/m \approx 1.7 \times 10^{11}$ s^{-1}.

For current which is formed by charges moving along the trajectory, we can derive simple formula using the physical ingredients in the preceding text. $J = e(N/L)v_{drift} = e(1/2\pi R)v_{drift} = 1.6 \times 2.8 \times 10^{-9}\text{A} \approx 4.5 \times 10^{-9}$ A.

We see, that the current generated by the high-intensity field with only one electron at the arc of the cycloid is very small. However for $e \to 10^{10}e$, we obtain $J = 45$ A

If the distribution of the synchrotron is $P(\lambda)$, then, the maximal intensity of radiation is is for the following $\lambda = \lambda_{max}$ [4]:

$$\lambda_{max} \approx (4\pi/3)R\left(\frac{mc^2}{W}\right)^3, \tag{32}$$

where R is the radius of the circle and W is the energy of electron with the rest mass m which moves along the circle.

If we assume that MAGFEL works at above conditions then, with the electron rest energy $mc^2 = 0.5$ MeV, and $W \approx 0.5$ MeV, we get:

$$\lambda_{max} \approx (4\pi/3)R \approx 23.9 \times 10^{-6}\ \text{m} = 23.9\ \mu\text{m}, \quad B = 1\text{T}, \tag{33}$$

which is the infrared wavelength.

However, the synchrotron radiation is generated in the form of all wavelength and it means also for $\lambda < \lambda_{max}$. It means that the planar magnetron generates also the Roentgen radiation. Of course, the intensity of the Roentgen radiation of one electron is very weak. However, in case with many electrons, it can be very strong and it differs from the laser radiation, which is produced in the optical frequencies. So, the practical application of the planar magnetron as a source of the Roentgen, or, synchrotron radiation is possible.

6 The use of MAGFEL for the therapy of cancer

We know [10] that the usual methods of the cancer therapy are by surgeon way, biochemical and radiological. Radiotherapy, or, therapeutic radiology is the treatment of disease with penetrating radiation, such as X-rays, beta rays, gamma rays, proton beams, pion beams and so on. Specially, high energy protons have ideal characteristics for treating deep-seated tumors [11]. The rays are usually produced by machines, or by the certain radioactive isotopes. Beams of radiation may be directed at a diseased object from a distance of radioactive material. Well known technique is Leksell gamma knife [12]. At present time it uses approximately 200 sources of the gamma rays where gamma rays are produced by radionuclides ^{60}Co. Many forms of cancer are destroyed by this type of radiotherapy.

At present time the successful method is to treat cancer by the synchrotron radiation generated by synchrotrons, betatrons and microtrons. We proposed in this article, the planar magnetron laser, MAGFEL, as the new medicine element for treating the cancer. The size of the planar megnetron is in no case so large as the synchrotron and it means the cancer tumors can be negated by the ambulatory way. So, the cancer therapy by MAGFEL is perspective one.

7 Discussion

The generation of the synchrotron radiation by the planar magnetron, forms the analogue of the wiggler and undulator generation of radiation [13]. However, while the wiggler and undulator radiators needs the high-energy electrons from additional accelerator, the planar magnetron works with electrons which are accelerated by own magnetic and electric fields. The acceleration depends on the intensity of electric field, and, the curvature of trajectory depends also on the magnetic field. The spectrum of the magnetron radiation in system S' moving with the drift velocity $v_{drift} = cE_y/H$, is the spectrum of the synchrotron radiation of N electrons moving along the circles of the same radius. According to the special theory of relativity, there is only the magnetic field in the system S'. MAGFEL works with the single electron on the trajectory, or, with many electrons on one trajectory, or many trajectories. In case of many electrons the radiation can be very intensive. The merit of the MAGFEL is in small size with regard to the large synchrotrons. On the other hand the opening angle of radiation is not so small as in the synchrotron because electrons in MAGFEL are nonrelativistic. The small opening angle is possible only for high energy electrons. According to Winick [13], if an electron is given a total energy 5 GeV, the opening angle over which synchrotron radiation is emitted is only 0.0001 radian, or about 0.006 degree. This can be regarded as a beam with the nearly parallel rays. This is practically the same as the laser beam situation. The wave length of the magnetronic photons is from zero to infinity. If we want to produce maximal energy of photons at the very short length of photons, then we must apply in MAGFEL very high magnetic field and very high voltage. If we use high-frequency high-voltage alternate current generated by the Tesla transformer, then we must also alternate the magnetic field in order to keep the motion of electrons in one direction. This can be easily realized, because the $x(t)$ is invariant with regard the simultaneous alternating the electric and magnetic field, as we can see:

$$\frac{cE_y}{H} \to \frac{c(-E_y)}{(-H)}, \quad \omega_0 \to -\omega_0. \tag{34}$$

The variable y is not invariant with regard to the transformation (34). It is $y(t) \to -y(t)$. However, the prismatic protrusion causes that only trajectories with the positive electric and magnetic fields are realized.

It follows from formula (28) that MAGFEL produces all wave lengths including synchrotron radiation and visible light. Using optical filters we can leave only the short wave lengths. Of course, then, the total applied radiation is decreased. Such synchrotron radiation from MAGFEL can have the similar function as the synchrotron facilities in BESSY (Berlin), Maxlab (Lund), Advanced Light Source (Berkeley), NSRRC (Taiwan, Hsincu), Australian Synchrotron (Melbern) and others, which are used as the photoemission spectroscopy devices applied in the solid state physics [14]. It is evident that MAGFEL is cheaper than the prestigious facilities and it can be installed in all small laboratories.

In conclusion, we should like to remark that the present article is the modification of the author e-print [15] where the theoretical proposal of MAGFEL is suggested. We hope, that MAGFEL will play relevant role in all branches of science.

References

[1] Landau L. D. and Lifshitz E. M., *The Classical Theory of Fields*, 1962 2nd ed. Pergamon Press, Oxford.

[2] Jackson J. D., Classical Electrodynamics, 1998 3-rd. ed. John Wiley and Sons New York etc.

[3] Schwinger J., Tsai W. Y. and Erber T., Classical and quantum theory of synergic Synchrotron-Čerenkov radiation, 1976 *Annals of Physics* (*New York*) **96** 303.

[4] Schwinger J., On radiation by electrons in a betatron, 1945 *preprint LBNL-39088 CBP Note-179 UC-414*.

[5] Schwinger J., On the classical radiation of accelerated electrons, 1949 *Phys. Rev.* **75** No. 12 1912 - 1925.

[6] Pardy M., Synchrotron production of photons by a two-body system, 2000 *International Journal of Theoretical Physics* **39** No. 4 1109 [hep-ph/0008257].

[7] Pardy M., Largest terrestrial electromagnetic pulsar, 2002 *International Journal of Theoretical Physics* **41**(6) 1155.

[8] Rohlf J. W., *Modern Physics from α to Z^0*, 1994 John Wiley & Sons Inc. New York.

[9] Wille K., *The Physics of Particle Accelerators - an introduction*, 2000 First ed. in English Oxford University Press.

[10] *Concise Medical Dictionary*, 2003 Oxford university press.

[11] Jones D. T. L. and Schreuder A. N., Magnetically scanned proton therapy beams: rationales and principles, 2001 *Radiation Physics and Chemistry* **61** 615-618.

[12] Leksell L., The stereotaxic method and radiosurgery of the brain, 1951 *Acta chir. Scan.* **102** 316-319.

[13] Winick H., Synchrotron radiation, 1987 *Scientific American* **257**, November pp. 72 -81.

[14] Reinert F. and Hüfner S., Photoemission pectroscopy - from early days to recent applications, 2005 *New Journal of physics* **7** 97-34.

[15] Pardy M., Theory of the magnetronic laser, 2003 [physics/0306024]