An RF Gun as a Polarized Source for Tesla

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Abstract. The possibility to use an rf gun as a source of polarized electrons for Tesla is studied. Potential limitations to consider, when a GaAs cathode is used in an rf gun environment, are examined with respect to the requirements for Tesla.

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ABSTRACT

The possibility to use an rf gun as a source of polarized electrons for Tesla is studied. Potential limitations to consider, when a GaAs cathode is used in an rf gun environment, are examined with respect to the requirements for Tesla.

The Tesla proposal for a future high energy linear collider demands an unusual long train of 1130 electron bunches with a large bunch-to-bunch spacing of 707 ns, a single bunch charge of 6 nC, and an rms length 0.7 mm.

At present, all polarized electron sources are using dc guns generating long pulses, usually followed by a bunching system (see e.g. [1]). An attractive source for electrons for Tesla is the use of an rf gun rather then a dc gun. Rf guns have produced short bunches with high charge similar to those required for Tesla. At the Tesla Test Facility [2] an injector for unpolarized electrons is under construction, which uses an L-band rf gun. So far, GaAs was not used in rf guns. One reason was the high sensitivity of the activated GaAs to contaminations [3]. An ultra-high vacuum of better than $1 \cdot 10^{-11}$ mbar must be maintained in the rf gun, which is not the case in existing rf guns. Suggestions have been made to overcome this problem leading to a first proposal using rf guns as a source for polarized electrons [4]. A successful attempt has recently been made to test a GaAs crystal in an rf gun [5]. Other potential problems when using GaAs as a cathode material have to be considered (see also [5]): the space charge and current density limit, multi bunch effects, the response time, the quantum efficiency and the laser system.

The space charge limit estimated from Gauss' law is in the order of $35\,\mathrm{nC/cm^2}$ for an L-band rf gun operating with an extraction field of 40 MV/m. This is well above the requirements for Tesla. A more severe limitation specific to GaAs-type cathodes is the so called "cathode charge limit" [6] which is in the case of short excitation pulses practically a current density limit [5]. This limit is typical for semiconductor cathodes with a negative electron affinity (NEA) surface. The limit can be understood as a competition between the rate of near-thermal electrons arriving from the conduction band at the surface and the discharge rate of electrons from the surface [7]. Since the current density limit would increase with the discharge rate from the surface, it is preferable to use the highest possible extraction field. Also a larger cathode surface and longer pulses will lower the current density. The current density limit for the Tesla case can be estimated using SLC data [8]: the SLC gun produces about 10 nC in a 2 ns long pulse from a GaAs cathode of an area of $1.5\,\mathrm{cm^2}$ close to the cathode charge limit. The acceleration voltage is 1.8 MV/m. From this data, the current density is limited to $3.3\,\mathrm{A/cm^2}$. Since the current density

Table 1: Shown are examples of parameter sets, for which the current density is at the limit of $3.3\,\mathrm{A/cm^2}$ as measured at the SLC gun. E is the accelerating voltage, A the cathode surface, and σ_t the pulse length (fwhh).

E (MV/m)	A ($\mathrm{cm^2}$)	σ_t (ps)	remarks
40	π	26	reasonable L-band choice
40	13	6	largest cathode L-band
40	2.1	40	longest pulse length L-band
50	π	21	highest field L-band
70	2.5	20	S-band: all parameters at limit

limit scales linearly with the acceleration voltage E [9], it is convenient to express the current density limit for the Tesla case (bunch charge of 6 nC) in the following expression

$$E\ A\ \sigma_t \geq 3.3$$

with E in MV/m, the cathode surface A in $\mathrm{cm^2}$ and the fwhh pulse length σ_t in ns. Table 1 shows examples of combinations of E, A and σ_t for which the current density is at the limit of $3.3\,\mathrm{A/cm^2}$. For an L-band gun, several parameter choices fulfill the condition. It is not completely impossible to find a parameter set for an S-band gun, but one has to choose all the parameters at their limits. For multi bunch operation, an additional effect of the cathode charge limit gets important: the temporary flattening of the bands in the band bending region due to trapped electrons in the surface states, preventing further electrons from being extracted. Experiments at the SLC have shown, that the recovery time of the cathode is in the order of 10 to 100 ns depending on the cathode thickness [1]. This is much less than the Tesla bunch spacing of 707 ns.

The response time of NEA cathodes is usually large. The theoretical model described in [7], which is consistent with SLC data, gives an estimation of 20 ps to 7 ns. Experiments indicate response times as low as 10 ps for cathodes with a thin layer of 150 nm [10].

A polarized electron beam is produced by applying circular polarized laser light on a strained lattice GaAs cathode. SLC data show [11] a polarization maximum of more than 80 % at a laser wavelength of 845 ± 10 nm. Unfortunately, the quantum efficiency drops sharply for highest polarization to $0.1 \ldots 0.3$ %. In addition, the quantum efficiency depends strongly on the operating conditions of the gun. High dark current of more than 50 nA [1] and poor vacuum conditions reduces the quantum efficiency significantly. In addition, activation of the cathode by cesiation is regularly required. To obtain a reasonable up time of the source, a load lock system, which enables cesiation or cathode changes without breaking the gun vacuum is essential. Such a system will be tested for the TTF rf gun.

Most polarized electron sources use lasers based on Ti:Sapphire. For Tesla, a long bunch train of almost 1 ms length has to be generated. This is very unusual for common lasers and requires a special design. For the TTF rf gun, such a laser system is under construction [2]. For long pulse trains, a laser material with good thermal properties like low thermal lensing is preferred. The strong thermal lensing of Ti:Sapphire would lead to a variation of the focusing of the laser beam during the pulse train resulting in an undesired ununiformity. Other laser materials, which are tunable in the required wavelength range are Cr:LiCAF and Cr:LiSAF. Their advantage is the low thermal lensing and the possibility to be pumped by flash lamps and laser diodes. In the proposal for the TTF laser system, a laser based on Cr:LiSAF/Cr:LiCAF, which would fulfill the energy and bunch structure requirements, has already been discussed [12].

Despite the difficulties to operate an rf gun under ultra-high vacuum conditions, it can be concluded, that a GaAs cathode is suitable – from the present knowledge – to generate the required polarized electron bunch train for Tesla. However, experiments under the required conditions have not been undertaken yet. Especially the assumption based on SLC data [9], that the current density limit scales linearly with the applied acceleration field has to be verified for higher gradients in an rf gun. Due to the current density limit, an L-band rf gun operating at its highest gradient is the preferred choice. A large cathode surface and long bunches of about 25 ps are required. It may be expected, that further developments of GaAs cathodes will looses the current density limit.

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