MATERIAL TESTS FOR THE ILC POSITRON SOURCE *

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Abstract

The positron source is a vital system of the ILC. The conversion target that yields about 10^{14} positrons per second will undergo high peak and cyclic load during ILC operation. In order to ensure stable long term operation of the positron source the candidate material for the conversion target has to be tested. The intense electron beam at the Mainz Microtron (MAMI) provides a good opportunity for such tests. The first results are presented for Ti6Al4V which is the candidate material for the positron conversion target as well as for the exit window to the photon beam absorber.

INTRODUCTION

The positrons for the future International Linear Collider (ILC) [1] are produced using a helical undulator. The undulator is passed by the high-energy electron beam to generate an intense, circularly polarized photon beam. The few-tens-MeV photon beam hits a target of 0.4 radiation length to create electron-positron pairs. The positrons are collected and accelerated. Special demands arise for the positron target since the photon beam is highly focused and has a power of the order of 50–100 kW. Although only 5–7% of the beam energy are deposited in the target, the density is so high that the target must be moved with 100 m/s to distribute the heat load to a larger volume. The target system is placed in vacuum; the preferred target material is Ti6Al4V. This alloy is stable against high temperatures and high mechanical load at operation temperatures of 300–400°C.

To avoid early failure or damage of the target, the material behavior must be tested under conditions as realistic as possible. Since there is no facility available which provides an intense photon beam with at least few MeV, the load in the target are simulated using an electron beam. At the injector of the Mainz Microtron (MAMI), electrons of 14 MeV are available. Focusing the electron beam, a temperature rise in a target sample can be achieved corresponding to that generated by the photon beam in the ILC positron target. By chopping the MAMI beam also the cyclic load can be simulated.

Based on the expected load at the ILC target material tests are performed using the 14 MeV MAMI beam. Here, the procedure and first results are presented.

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LOAD AT THE ILC POSITRON TARGET

The ILC superconducting helical undulator has a period of 11.5 mm, allows K values of up to 0.92 and is planned with a magnet length of up to 231 m. This allows generating the amount of photons required to produce 1.5 positrons per electron. The energy deposition of the photon beam in the positron target was calculated with FLUKA [2]. The pulse length at the ILC is 0.727 ms (1312 bunches, 554 ns bunch spacing), the peak energy deposition density in the target is about 45 J/g for the nominal luminosity, corresponding to a maximum instantaneous temperature rise of 84 K along the beam path through the target. The target is designed as a wheel of 1 m diameter spinning with 2000 rounds per minute; so one bunch train of the photon beam is distributed at the rim along 8–10 cm. With a repetition rate of 5 Hz the photon beam hits every 6–7 seconds the same area on wheel. This time is not sufficient to remove the heat from the target rim: the target temperature near the beam path increases to quite high equilibrium values depending also on the wheel design and cooling which are currently under consideration. Simulation studies showed that 600°C and even higher equilibrium values could be reached. Although Ti6Al4V offers excellent thermal and mechanical properties up to temperatures of 300−400°C, its resistivity against high cyclic load operation at higher temperatures has to be tested.

Target Material Test at MAMI

To simulate the electromagnetic shower in the ILC positron target the 14 MeV electron beam of the MAMI injector was used. The high peak load similar to that at the ILC was created by focusing the electron beam to small dimensions. Tests showed that the chopped 50 μA cw electron beam with pulse length of 2 ms could achieve the rms spot size on target $\sigma \approx 0.2$ mm. So, the same energy deposition density per pulse was achieved as expected for the ILC photon beam. The energy deposition in the ILC target happens much faster, within 50 μs. However, due to the spinning target the energy deposition density is not large enough to create serious shock phenomena in the material as studies with ANSYS showed. So, the conditions at the MAMI injector are sufficient for a first reliable study of the target material behavior. The MAMI pulse was repeated with 100 Hz to simulate within hours the cyclic load lasting for months at the positron source operation. For comparison, one ILC year with 5000 hours corresponds to about 2.8×10^6 load cycles at a certain position at the target.

Experiment

Ti6Al4V samples of 1 mm and 2 mm thickness were mounted on a movable holder and positioned in the beam-

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line. All samples had a width of 42 mm and a height of 14 mm, with two holes of 1 mm and 0.5 mm diameter for an easier alignment. The samples were cut from a larger pad by electro-erosion. The surfaces of targets 3 were softly milled. Figure 1 shows the arrangement of the samples at the holder.

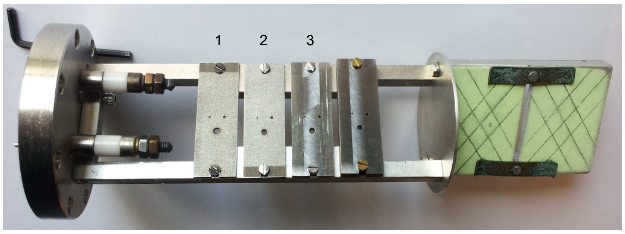

Figure 1: Arrangement of the target samples on the aluminium holder.

The size of electron beam was determined by measuring the target current when the beam was passing through the middle of target hole. Two samples, target 1 and target 3, were mounted without thermal contact to the holder, i.e. isolating ceramics was placed between sample and holder. Target 1 was equipped with thermocouple to measure the temperature. The thermocouple was fixed 5 mm away from the line connecting two holes. The experimental conditions and irradiation times are shown in Table 1.

Table 1: Overview of irradiation time, conditions, and results for the two samples mounted thermally isolated on the target holder.

	Target 1	Target 3
Target thickness [mm]	1	2
Peak current [μA]	50	
Pulse length [ms]	2	
Rep. rate [Hz]	100	
Irradiation time [min]	1108	862
Number of cycles [10^6]	6.648	5.172
T_{max}^{ave} [°C]	629	713
T_{peak} [°C]	690	772
ΔT/pulse [K]	61	59
$\Delta\sigma_{normal}^{max}$ per cycle [MPa]	230	210
ε_{max} (front side) [μm]	≤ 15	≤ 28
ε_{max} (exit side) [μm]	~ 0	≤ 15

Results

The energy deposition of the 14 MeV electron beam in the target samples was simulated with FLUKA. The resulting average heating, the peak temperatures as well as the stress were studied with ANSYS [3]. These simulations include the temperature dependence of the thermal conductivity and heat capacity taken from reference [4]. A comparison of the simulated temperature distribution at the target with the temperature measured by the thermocouple indicates an emissivity of $\epsilon = 0.7$. The detailed measurement of the emissivity is foreseen in due course. Figure 2 presents the temperature evolution in time. Figure 3 shows the temperature distribution for the 2 mm thick sample. The large temperature difference between the beam spot area and the regions away that point are due to the low thermal conductivity of Ti alloys. Table 1 summarizes the irradiation of the two samples 1 and 3 and indicates the surface changes after irradiation.

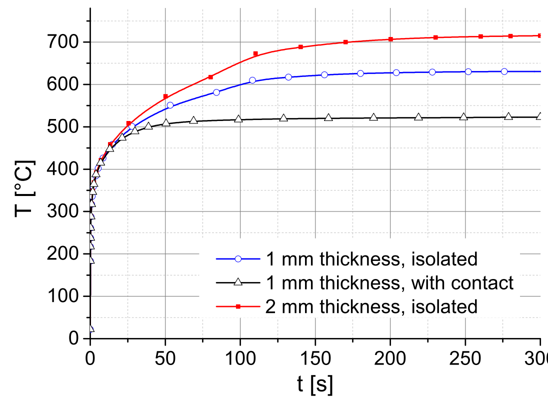

Figure 2: Evolution of the maximum temperature vs. time in target samples with and without thermal contact to the holder simulated using ANSYS.

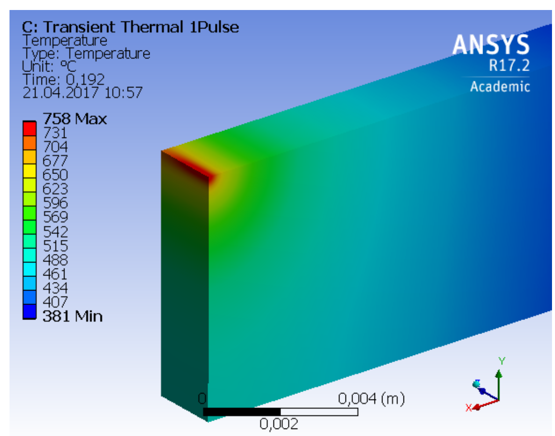

Figure 3: Temperature distribution in the target 3 sample after the end of a pulse simulated with ANSYS.

All samples survived the irradiation procedure without damage visible by eye; some color was obtained around the beam path, distinctly and visible for target 3. Figure 4 shows the targets after irradiation.

Figure 4: Photo of the targets after irradiation.

The samples were inspected with a scanning electron microscope and a laser scanning microscope. The investigation of target surfaces manifested the dimensional changes ε in the area of highest temperature up to about 30 μm for the target 3 which was mounted thermally isolated on the holder. Target 2 (1 mm thickness) was directly mounted on the holder made of aluminium. No changes at the surface of target 2 were obtained after 5 hours of irradiation with pulses of 3 ms, 66.7 Hz and 50 μA peak current. This irradiation scheme yields the same average power deposition in sample 2 as in sample 1, but the cooling of the sample 2 is more effective due to the thermal contact to holder. So the average temperature in target 2 was below that of target 1, which was cooled only by thermal radiation to the vacuum chamber.

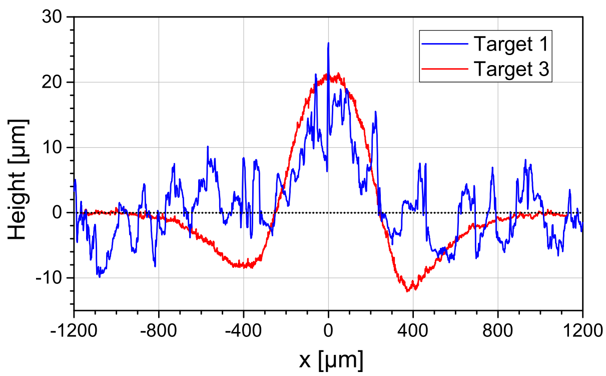

Figure 5: Deformation (difference of height) obtained in the beam area at the front side of targets 1 and 3. $x = 0$ - beam center; height = 0 - height level of target surface far from the beam (unirradiated target area).

Figure 5 presents the surface profiles at front side of targets 1 and 3. Since the energy deposition density and the temperature rise per pulse in these samples are approximately the same, the average temperature is considered as the reason for the dimensional change. Temperatures above 700°C correspond to annealing temperatures for Ti6Al4V alloy. The structural changes are likely upon exceeding this value. This explanation is supported by the grain growth obtained in target 3 in the hottest area. Figure 6 presents difference in the target grains. The maximal grain area in the beam is 982 μm^2 against 291 μm^2 for the grains in the target region far from beam. The average grain area in the beam is approximately 50 μm^2 that is a factor 2.6 larger than in the region away from beam.

Such recrystallization (growth of grains) is typical for the Ti-alloy material above 700°C. It remains to test whether thermal and mechanical properties of the material become degraded strongly so that the material could be damaged seriously.

SUMMARY AND OUTLOOK

The experiment at MAMI demonstrated that Ti6Al4V stands a long-term irradiation with high cyclic load as expected at the ILC positron production target. At temperatures above 700°C dimensional changes in the region around the beam path are obtained. The design of ILC components made of Ti6Al4V, in particular the positron target, must ensure that the temperature remains below 700°C. In further studies it is intended to clarify whether these changes also influence the creep properties and other parameters important for the construction of the spinning target wheel. Since a high cyclic stress at ILC exit windows is expected too, further studies will include the performance of thin Ti and Ti-alloy layers under the irradiation conditions similar as expected at ILC.

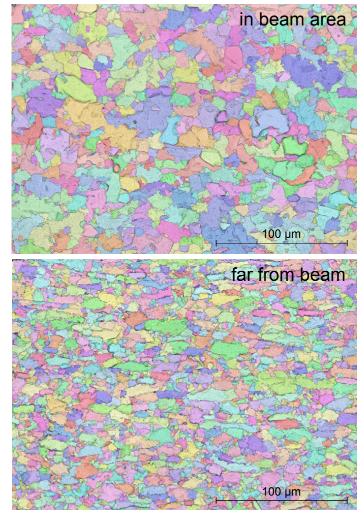

Figure 6: Grain sizes measured in the hot region where the beam passed the target 3 (upper plot) and distant from that point (lower plot).

ACKNOWLEDGEMENT

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