



Possible tests in KEK facilities for LC positron generation

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- ▶ Target damage in positron generation driven by electron beam caused by two mechanisms:
 - ▶ **Acoustic shock wave**
 - ▶ **Temperature rise**



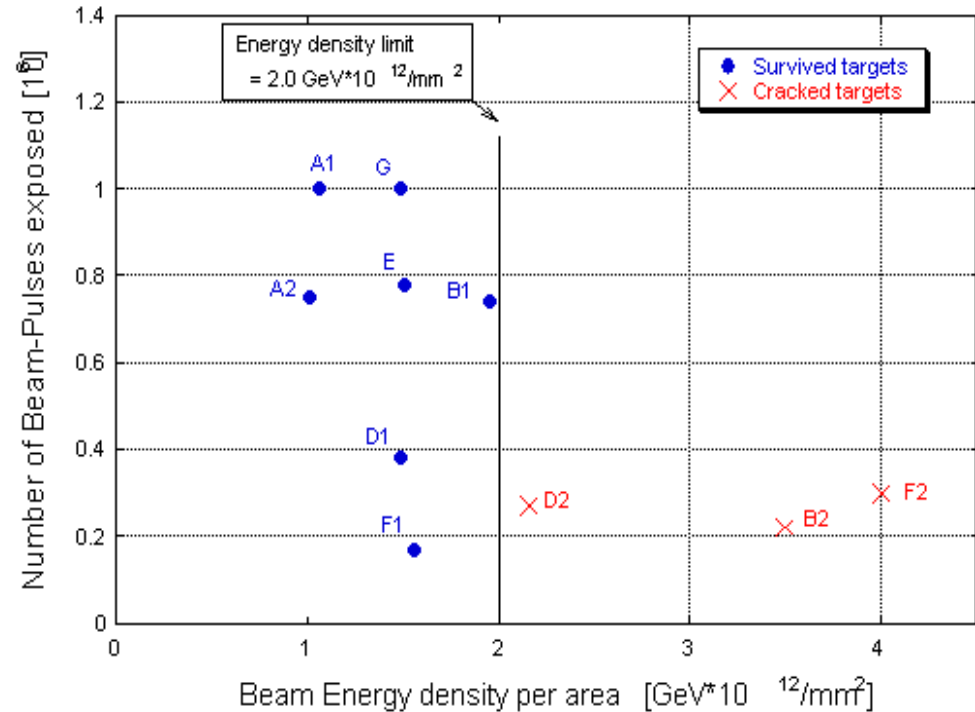
Acoustic shock wave

- ▶ Acoustic wave in material propagates with a specific speed.
- ▶ It takes a few 100 ns, propagating over 1mm spot.
- ▶ The shock wave is “accumulated” on a spot over a few 100ns.

Material	V_l (km/s)	V_t (km/s)	L_{100ns} (mm)
W	5.41	2.64	5.41E-01
Be	12.9	8.88	1.29E+00

Damage Threshold

- ▶ The damage threshold depends on beam energy density per bunch; It does not depend on # of exposures.
- ▶ Damage threshold for short bunch : 20GeV, 16nC ~ 320J/mm² (35J/g) for W(75)Re(25) alloy.
- ▶ 320 J/mm² can be thought to be a limit of the acoustic wave effect.



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Peak Beam Energy Density

- ▶ The effect of the acoustic shock wave is characterized by a parameter defined as

$$\eta = \frac{E(\text{GeV}) \times N(\text{nC})}{S(\text{mm}^2)}$$

- ▶ The peak beam energy density is summed up in several 100ns window.
- ▶ The limit can be 320 J/mm².

Temperature rise

- ▶ Temperature rise is evaluated from the energy deposition density of the drive beam, heat capacity, and Fourier equation, which express thermal diffusion.
 - ▶ Not only the melting due to the higher temperature than the melting point, but also the stress due to the temperature gradient is problem.
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Fourier equation (1)

Thermal conduction is expressed by energy density ρ (J/m³) and flow J (W/m²)

$$\frac{\partial \rho}{\partial t} = -\nabla \cdot \vec{J}$$

Temperature T (K) is given by

$$\rho = C_v T$$

where C_v (J/m³K) is heat capacity. Thermal flow J is expressed with thermal conductivity λ (W/m.K)

$$\vec{J} = -\lambda \nabla T$$

Finally,

$$C_v \frac{\partial T}{\partial t} = -\lambda \nabla \cdot \nabla T$$



Fourier equation (2)

Fourier equation is rewritten as

$$\frac{\partial T}{\partial t} = -\Lambda \nabla \cdot \nabla T$$

which has a particular solution

$$T(x, t) = T_0 \exp(\alpha t + i\beta x)$$

$$\alpha = -\Lambda \beta^2$$

α (1/s) is a time constant of thermal diffusion and β (1/m) gives a specific length of the dimension. The time constant depends on not only the material properties, but also the specific length (spot size).



BN, Pb-Sn

- ▶ BN has a very good thermal conductivity as same as diamond. 1500 W/m.K is assumed.
- ▶ Heat capacity is unknown. B has 0.245 and N₂ has 0.249 (cal/g.K). 0.25 (cal/g.K) is assumed.
- ▶ Density is 3.48 (g/cm³).
- ▶ Heat capacity is 3.65E+6 J/m³K.

	λ (W/m.K)	C_v (J/m ³ K)	λ/C_v (m ² /s)
BN	1.50E+03	3.65E+06	4.11E-04
Pb	35.3	1.81E+06	1.95E-05
Sn	66.8	1.56E+06	4.28E-05
Pb _{0.9} Sn _{0.1}	38.5	1.79E+06	2.15E-05

Thermal diffusion

- ▶ According to Fourier equation, thermal diffusion is determined by Λ and β .
- ▶ For $\beta=1E+3$ (1/m), α and τ are evaluated.
- ▶ The time constant is in order of ms – 10 ms.

	Λ (m ² /s)	α (1/s)	τ (s)
BN	4.11E-04	4.11E+02	2.43E-03
Pb	1.95E-05	1.95E+01	5.13E-02
Sn	4.28E-05	4.28E+01	2.34E-02
Pb _{0.9} Sn _{0.1}	2.15E-05	2.15E+01	4.65E-02



Effective Beam Energy Density

- ▶ Temperature rise at $t=0$ is ρ/C_v .
- ▶ If the energy deposition density is proportional to the beam energy density (J/mm^2), it can be used instead of the exact energy density.
- ▶ Including effect of thermal diffusion, Effective Beam Energy Density ρ_{beam} (J/mm^2) is defined as

$$\rho_{\text{beam}} = \frac{E_{\text{beam}} Q}{S \left[1 - \exp\left(-\frac{t_b}{\tau}\right) \right]}$$

where t is bunch or pulse interval. If $t \ll \tau$,

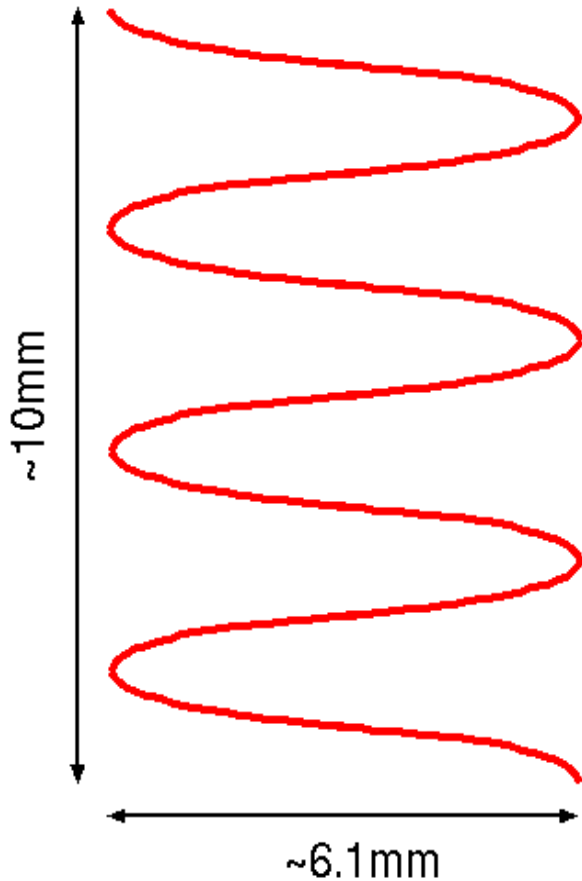
$$\rho_{\text{beam}} = \sum \frac{E_{\text{beam}} * Q}{S}$$

- ▶ $t_b=369\text{ns}$ and $t_p=200\text{ms}$.
- ▶ $t_b \ll \tau$ and $t_p \gg \tau$
- ▶ Beam spot is assumed to be 2.5mm radius.
- ▶ $\eta=0.504 \text{ J/mm}^2$.
- ▶ ρ_{beam} is $2.2 \text{ GeV} \times 4.5\text{nC} \times 2625/\pi 2.50^2=1.30\text{E}+3 \text{ J/mm}^2$.

- ▶ $t_b=6.15\text{ns}$ and $t_{p1}=3.3\text{ms}$ and $t_{p2}=134\text{ms}$.
- ▶ $t_b \ll T$, $t_{p1} \approx T$, and $t_{p2} \gg T$.
- ▶ Beam spot is 2.5mm radius (rms).
- ▶ $\eta=26.0\text{J/mm}^2$.
- ▶ ρ_{beam} is

$$\epsilon_{\text{beam}} = \frac{5 \times 3.2 \times 132 / 19.6}{1 - \exp\left(-\frac{3.3}{3.3}\right)} = 1.72\text{E}+2 (\text{J/mm}^2)$$

KEKB Beam Dump



- ▶ HER: 8GeV, 10nC, 1300 bunches.
- ▶ Bunch spacing 6 or 8 ns.
- ▶ Beam size is 0.6x0.3mm, $S=0.57\text{mm}^2$, but it may be larger by scattering in air; 1mm^2 is assumed.
- ▶ $\eta=116 \text{ J/mm}^2$.
- ▶ 23-172 bunch overlap gives $\rho_{\text{beam}} 1.81\text{E}+3 - 1.37\text{E}+4 \text{ J/mm}^2$.

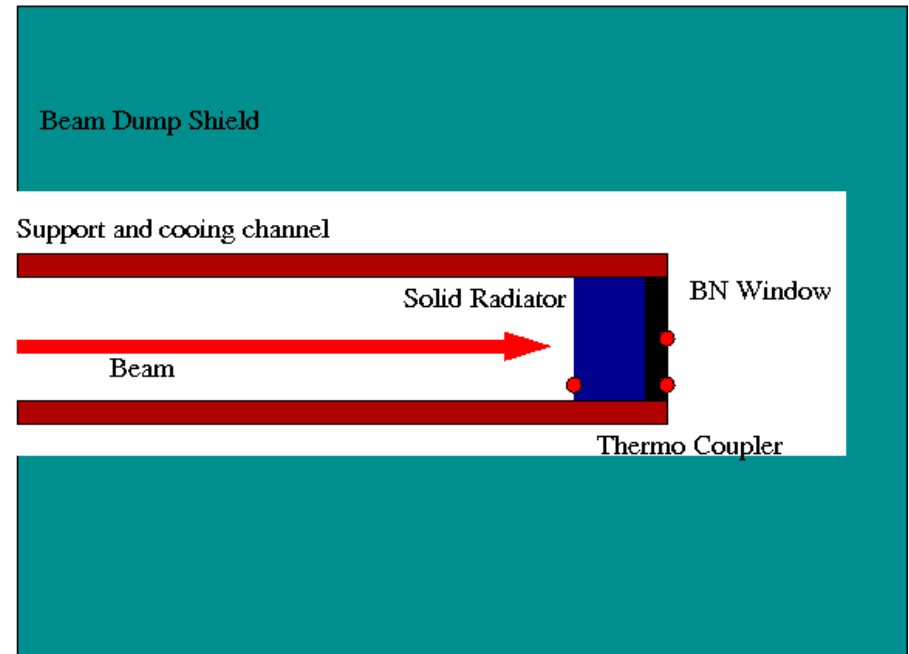
- ▶ 1.3 GeV, 3.2nC, 20 bunches, 2.8ns spacing.
- ▶ If the emittance is 10π mm.mrad and $\beta=1$ m, the beam spot size is $110\mu\text{m}$.
- ▶ $\eta=2.19\text{E}+3$ J/mm².
- ▶ $\rho_{\text{beam}} = 2.19\text{E}+3$ J/mm²

Possible tests

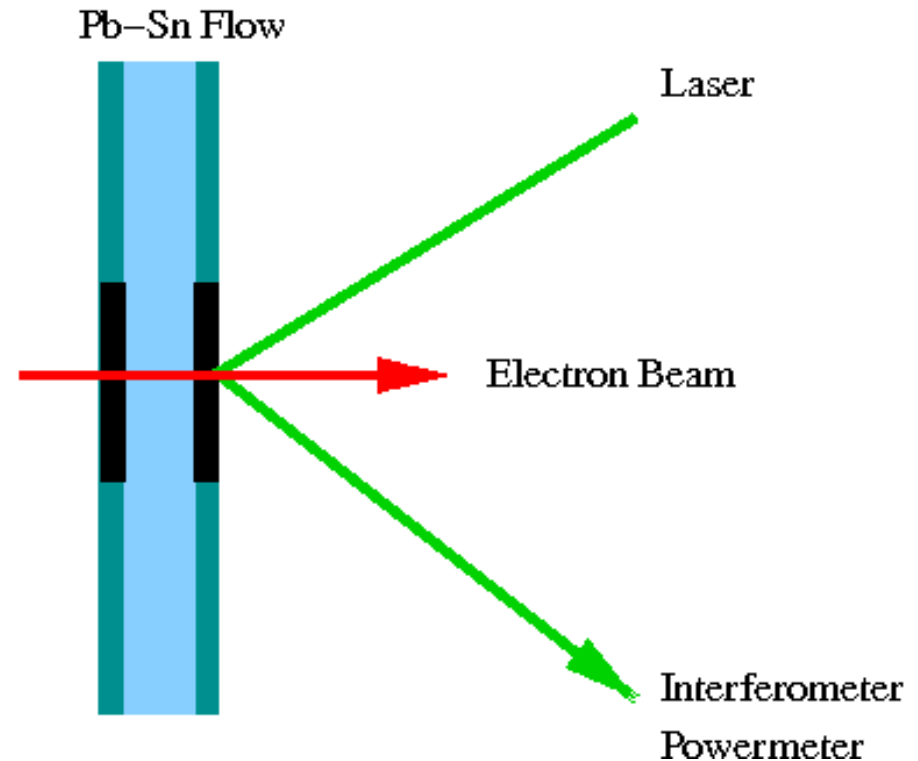
- ▶ Beam Energy Density on the positron production target for ILC positron generation is reproduced by KEKB and ATF.
- ▶ ATF operation is up to 6.25Hz.
- ▶ KEKB BD at 123mA is shot/41s.
- ▶ KEKB BD at 16.3mA is shot/6s.

	$\eta(\text{J}/\text{mm}^2)$	$\rho_{\text{beam}} (\text{J}/\text{mm}^2)$
RDR 2.2GeV	5.00E-01	1.30E+03
300Hz	2.60E+01	1.70E+02
KEKB	5.82E+01	1.81E+3-1.37E+4
ATF	2.19E+03	2.19E+03

- ▶ Space is very limited for KEKB BD.
- ▶ Solid Radiator is placed before BN plate.
- ▶ The sample is fixed with support rod, which also acts as cooling channel.
- ▶ It is difficult to place any equipments other than TC?

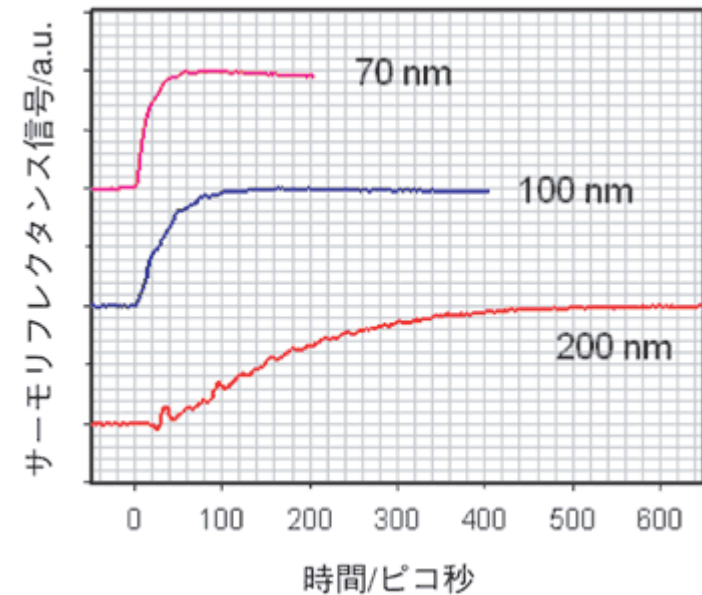
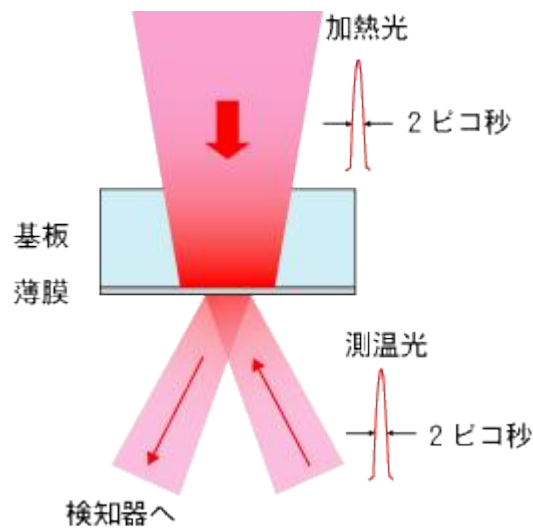


- ▶ In ATF, a prototype can be placed in the linac end.
- ▶ Temperature evolution can be measured with thermo-reflectance method. Metal thin film is evaporated on BN window surface.
- ▶ Acoustic deformation is also measured by interferometer.



Thermo-reflectance method

- ▶ Refractive index depends on temperature.
- ▶ By measuring reflection from thin-film of well-known material (e.g. metal), temperature can be measured.
- ▶ By using focused pulsed laser, time and spatial evolution are measured.



http://www.aist.go.jp/aist_j/aistinfo/aist_today/vol03_11/p13.html

Summary

- ▶ The effect on the positron production target can be qualified by peak beam energy density (η) and effective beam energy density (ρ_{beam}).
- ▶ The target vitality can be examined at KEKB BD or ATF Linac.
- ▶ By considering availability and duty cycle, ATF Linac is more feasible than KEKB BD.
- ▶ Experiment at ATF is also feasible for wide variety of investigation methods.