INFN Istituto Nazionale di Fisica Nucleare
SEZIONE DI MILANO

SPARC

SPARC-EBD -09/002
8 Novembre 2009

ENERGY DEPOSITION EFFECTS OF THE ELECTRON BEAM ON THE MIRROR OF PLASMON-X EXPERIMENT AT LIFE

Francesco Broggi, Luca Serafini

INFN-LASA-Sezione di Milano, Via F.lliCervi 201, 20090 Segrate, Italy

Abstract

LIFE (Laboratorio Interdisciplinare Fotoni ed Elettoni) is a facility in construction at the INFN Laboratori Nazionali di Frascati (LNF). The backbone of the facility will be the 20-150 MeV in 2-5 ps electron beam from SPARC and the FLAME (Frascati Laser for Acceleration and Multidisciplinary Experiments) laser, an 800 nm, 6 J energy laser with 300 TW peak pulse in 20 fs and a repetition rate of 10 Hz.

The laser in under commissioning while the electron beam is already available for the SPARC FEL experiment. Next year two additional beam lines will provide the electron beam to the PLASMON-X (where plasma acceleration experiment will be carried out, through the interaction of the electron beam with the FLAME laser) and a Thomson backscattering experiment.

A non perfect alignment of the electron beam can lead to a hit of the electron beam itself on the mirror.

The effect of the electron beam on the mirror, are investigated through the FLUKA code.

Under conservative hypotheses, no damage will occur to the mirror.

Work performed in the frame of the FLUKA collaboration and SPARC activity

1 INTRODUCTION

LIFE (Laboratorio Interdisciplinare Fotoni ed Elettoni), will be a multidisciplinary laboratory at LNF Frascati, where electron and photon beams from the SPARC (Ref.1) accelerator and FEL experiment will be available.

Another photon source will be FLAME laser (Ref.2), and the X photons from Thomson scattering experiment, as shown in Fig.1.

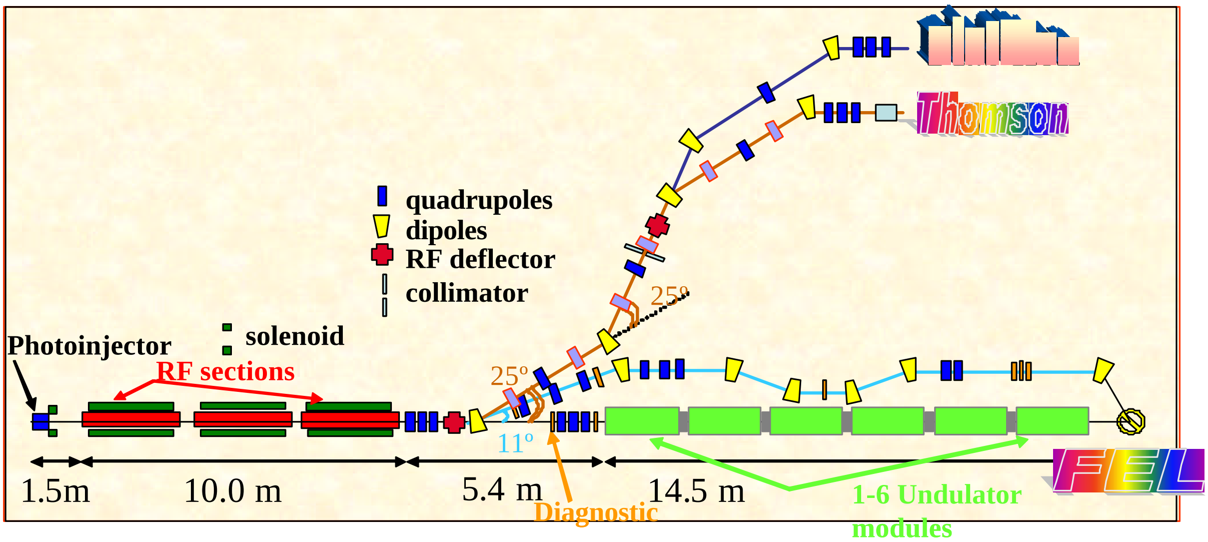

Fig.1 The SPARC/LIFE Facility

In Tab.1 the characteristics of the electron and photon beam are summarized.

Tab.1

ELECTRON BEAM (SPARC)	
Electron Beam Energy (MeV)	30-150
Bunch Charge (nC)	1
Rep rate (Hz)	1-10
Rms norm. transverse emitt. @ Linac exit (mm.mrad)	< 2
Rms longitudinal emittance (deg.keV)	1000
Rms total correlated energy spread (%)	0.2
Rms beam spot size @ Linac exit (mm)	0.4
Rms bunch length @ Linac exit (mm)	1
LASER BEAM (FLAME)	
Wavelength (nm)	800
Pulse Energy (J)	6
Pulse duration (FWHM) (fs)	< 30
Repetition rate (Hz)	10

The Thomson scattering occurs with an head on electron-photon interaction, to this aim the photon beam is reflected by an off-axis parabola mirror with a hole in its center in order to allow the passing through of the scattered radiation ad of the electron beam. The scheme of the interaction is shown in Fig.2.

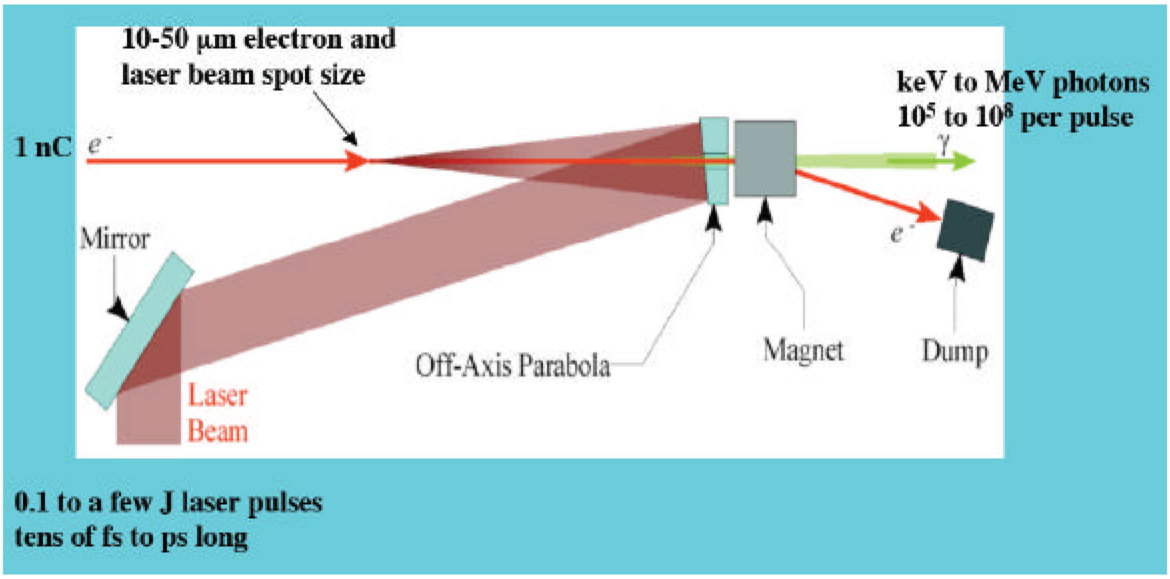

Fig.2 The PLASMONX interaction scheme.

Any misalignment or steering effect on the electron beam can drive it on the mirror.

The effect of the energy deposition of the electron beam on the mirror has been evaluated with the FLUKA code (Ref. 3,4), showing that no damage can occur at the mirror (either at the gold coating or at the glass bulk).

2 FLUKA GEOMETRY AND PARAMETERS

The drawing of the PLASMON-X mirror is shown in Fig.3. The electron beam comes from the right and makes a head on collision with the laser beam in the focus.

Then the beam goes through the hole in the mirror and is bent into a dump system by a bending magnet, located outside the interaction chamber. If the electron beam is not driven on the right trajectory, it sees the mirror in a cone of about 6° around the reference trajectory (at 20° respect to the axis). So the electron beam can hit the mirror under an incidence angle between 14° and 27°.

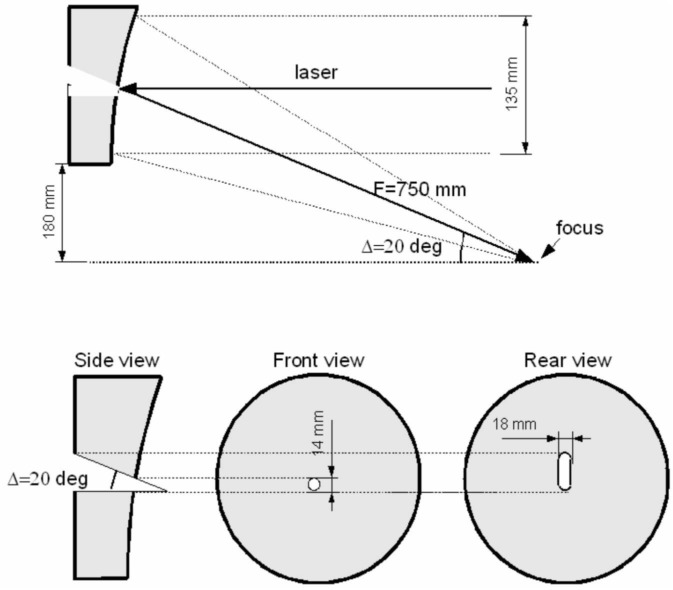

Fig.3 The PLASMONX mirror.

The schematization of the geometry used for the FLUKA simulation is shown in Fig. 4. The interaction occurs in a stainless steel chamber in vacuum, the mirror is located at about 70 cm from the interaction point, where the laser light (red), is downscattered (blue) by the electron bunch (grey).

The mirror is a Zerodur® bulk with a gold coating of about 20 µm thickness.

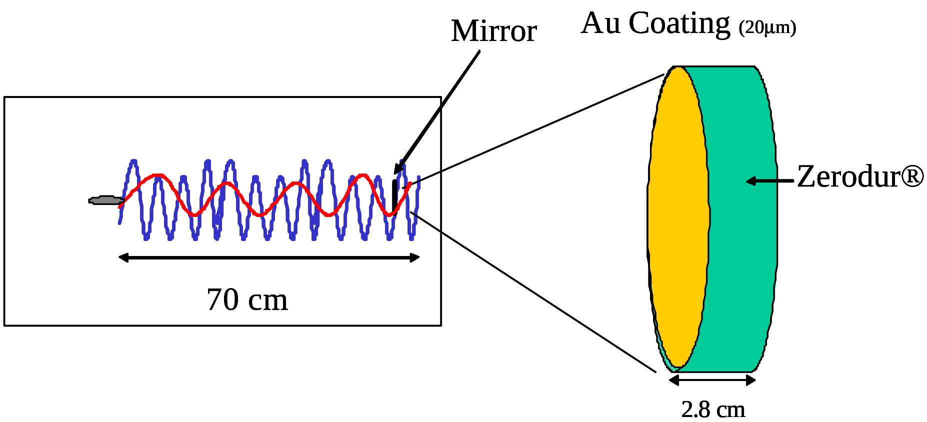

Fig.4 The FLUKA modelling of the interaction chamber.
The electron beam (grey), backscatter the incident laser light (red), the resulting radiation is shown in blue. At the right is the enlargement of the mirror.

As a conservative hypothesis no hole is foreseen in the mirror and the beam hits the mirror coating.

The mirror has been divided into subregions, in order to have an accurate energy deposition where the beam hits the mirror; one is an innermost cylinder with radius of about 2 mm both for the gold coating and for the Zerodur®, the other one is the remaining corona with an external radius of 2 cm (again for the coating and for the bulk), as shown in Fig. 5.

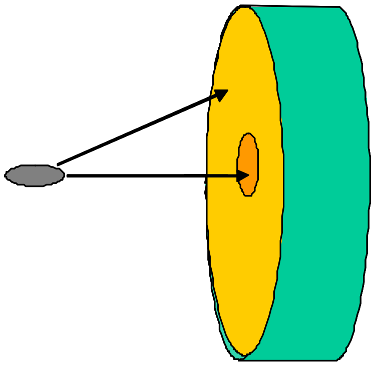

Fig.5 The Fluka modelling of the mirror with the subdivision of the regions.

The electron beam has normalized emittance of 2 mm·mrad, with a beam radius of about 5 µm at the interaction point and a divergence of about 2.2 mrad without any energy spread.

The composition of the Zerodur® bulk material listed in Tab.2 (Ref.5).

Tab.2.

ZERODUR®		
	Composition	
	wt (%)	mol (%)
SiO_2	55.4	63.9
Al_2O_3	25.4	17.2
Li_2O	3.7	8.5
Na_2O	0.2	0.2
K_2O	0.6	0.5
MgO	1.0	1.7
ZnO	1.6	1.3
P_2O_5	7.2	3.5
TiO_2	2.3	2.0
ZrO_2	1.8	1.0
As_2O_3	0.6	0.2

Different electron beam energies have been considered (3, 30 and 150 MeV).

The beam impinges normally on the mirror, and for the case 30 MeV the incidence of 27° has been considered too.

3 SIMULATION RESULTS

The results are obtained from 10 independent runs with 10^6 primary electrons each.

3.1 Energy Deposition

In Fig. 6 on the left a global view of the energy deposition map is shown for the beam energy of 3, 30 and 150 MeV respectively, in the case of orthogonal beam on the mirror. On the right column an amplified view of the energy deposition in the mirror is shown. The coating is just the first slab of the mirror and it cannot be seen on these scales.

The bin volumes are 1x1x1 cm^3 for the left plots and 0.04x0.04x0.028 cm^3 for the right plots.

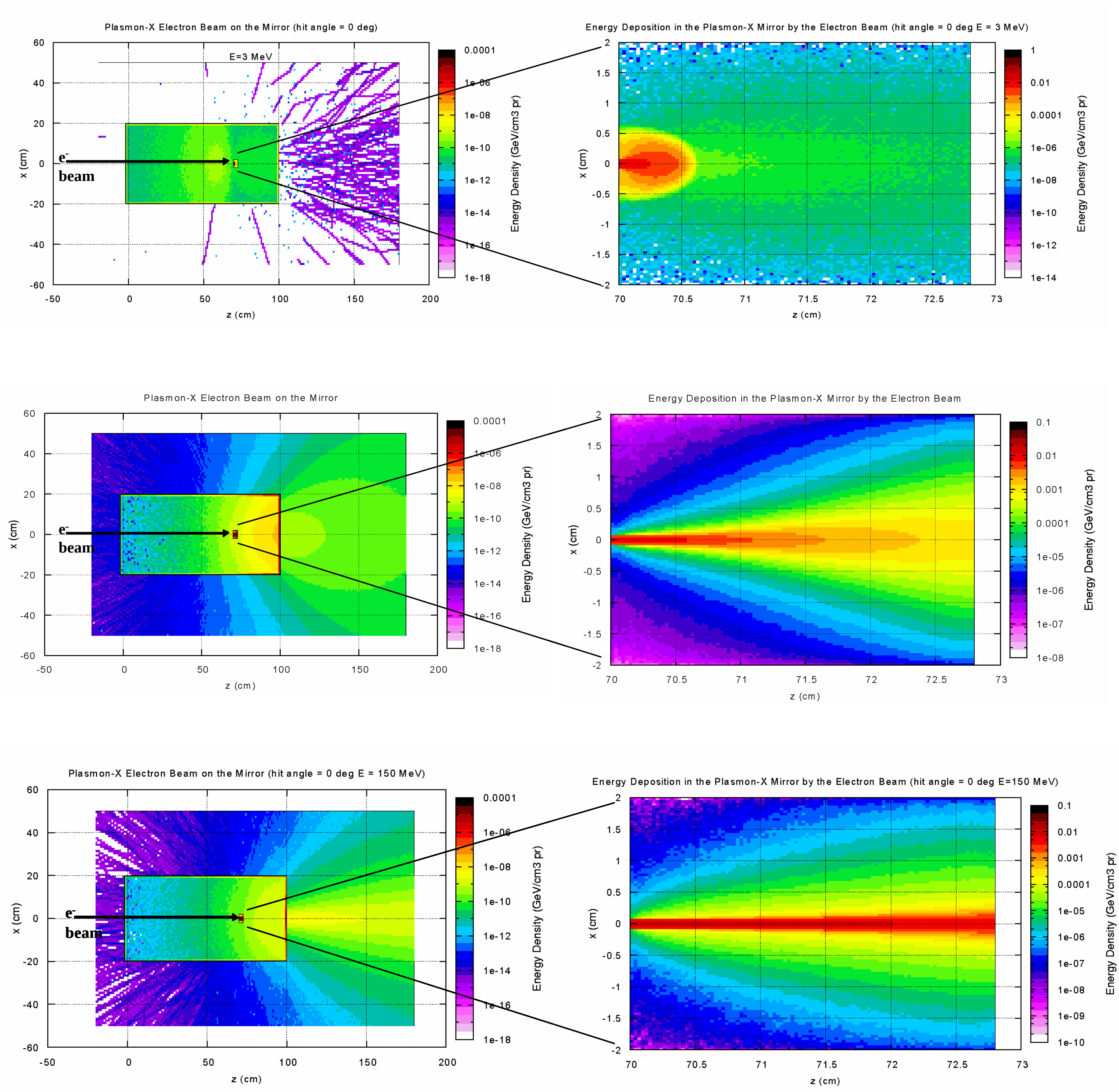

Fig.6. Energy deposition maps for 3 MeV electron beam (top), 30 MeV (middle) and 150 MeV (bottom). On the right an amplified view of the mirror only (bin dimensions of 1 x 1 x 1 cm^3 for the left plots, 0.04 x 0.04 x 0.028 cm^3 for the right plots have been used).

In Fig 7 the same plots as in Fig 6 for the 27 degree impinging angle of a 30 MeV beam are shown.

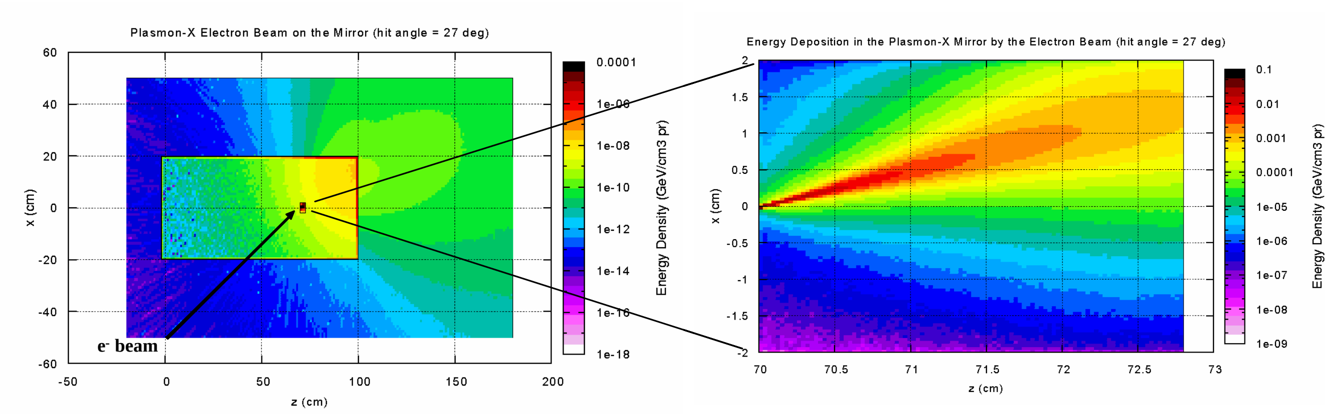

Fig.7. Energy deposition maps for 30 MeV electron beam hitting the mirror under 27° angle. On the right an amplified view of the mirror only. The bin dimensions are the same as in Fig .6

In the following table the amount of energy deposed in the mirror coating and bulk is summarized for the examined cases.

Case	Au Coating (GeV/pr or J/nC)		Zerodur® (GeV/pr or J/nC)	
	Inner part	Outer part	Inner part	Outer part
3 MeV 0°	4.76E-05±0.04%	4.65E-06±0.5%	1.85E-03±0.01%	1.01E-03±0.03%
30 MeV 0°	4.62E-05±0.04%	1.40E-07±2.27%	7.11E-03 ±0.02%	6.07E-03 ±0.04%
30 MeV 27°	5.19E-05±0.03%	2.68E-07±1.34%	1.92E-03±0.01%	1.22E-02±0.01%
150 MeV 0°	4.72E-05±0.03%	6.27E-08±2.27%	1.21E-02±0.005%	1.13E-03±0.05%

3.2 Temperature Increase

The temperature increase is conservatively evaluated by considering the region where the energy is deposed as a fully adiabatic one.

So the temperature variation per nC of electron beam in the inner part of the gold coating is given by:

$$\Delta T_{Au-\mathrm{int}} = \frac{Q}{mc_p} = \frac{5.19 \cdot 10^{-5}}{p\left(0.2 \cdot 10^{-2}\right)^2 \cdot 20 \cdot 10^{-6} \cdot 19.32 \cdot 10^3 \cdot 0.128 \cdot 10^3} = 0.08° / nC$$

Being 19.32 g/cm^3 Au density

0.128 x 10^3 J deg Kg^{-1} Au specific heat

The most critical part is where the maximum energy deposition (density) occurs.

The temperature increase is negligible; the same will be for the remaining part of the mirror coating and bulk.

The data refers to a deposition of 1 nC electron beam. At the highest repetition rate foreseen for the PLASMON-X experiment (10 Hz) the inner coating,

4 CONCLUSIONS

The simulations show that no danger will occur at the PLASMON-X mirror in case of hitting of the electron beam on the mirror.

The data refers to a deposition of 1 nC electron beam.

At the highest repetition rate foreseen for the PLASMON-X experiment (10 Hz bunches of 1.1 nC) the inner coating will not be damaged, being the temperature variation less than 1 degree.

Lower increases are to be expected in the remaining part of the coating and of the bulk material, so no the mirror will always operate in safe conditions.

Zerodur® is used in astronomy and astronautics because of its good thermal properties (low thermal expansion) (Ref.6), so no optical degradation of the mirror and of the whole PLASMON-X optics, due to thermal expansion, should be expected.

5 REFERENCES

(1) http:/ /www.lnf.infn.it /acceleratori / sparc /

(2) http:/ /www.lnf.infn.it /acceleratori /plasmonx /

(3) A.Fasso`, A.Ferrari, J.Ranft, and P.R.Sala, "FLUKA: a multi-particle transport code", CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773.

(4) A.Fasso`, A.Ferrari, S.Roesler, P.R.Sala, G.Battistoni, F.Cerutti, E.Gadioli, M.V.Garzelli, F.Ballarini, A.Ottolenghi, A..Empl and J.Ranft, "The physics models of FLUKA: status and recent developments", Computing in High Energy and Nuclear Physics 2003 Conference (CHEP2003), La Jolla, CA, USA, March 24-28, 2003, (paper MOMT005), eConf C0303241 (2003), arXiv:hep-ph/0306267.

(5) V.Maier, G.Muller, " Mechanism of Oxide Nucleation in Lithium Aluminosilicate Glass Ceramics “, J. Am. Ceram. Soc., 70 [8] C176-178 (1987).

(6) M. Viens, “Fracture Toughness and Crack Growth of Zerodur”, NASA Technical Memorandum 4185, April 1990.