DIAMOND MIRRORS FOR THE SUPERKEKB SYNCHROTRON RADIATION MONITOR

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Abstract

The SuperKEKB accelerator, a 40x luminosity upgrade to the KEKB accelerator, will be a high-current, low-emittance double ring collider[1]. The beryllium primary extraction mirrors used for the synchrotron radiation monitors at KEKB suffered from heat distortion due to incident synchrotron radiation, leading to systematic changes in magnification with beam current and necessitating continuous monitoring and compensation of such distortions in order to correctly measure the beam sizes[2]. The heat loads on the extraction mirrors will be higher at SuperKEKB, with heat-induced magnification changes up to 40% expected if the same mirrors were used as at KEKB. We are working on a design based on mirrors made of quasi-monocrystalline diamond, which has much higher heat conductance and a lower thermal expansion coefficient than beryllium. With such mirrors it is targeted to reduce the beam current-dependent magnification effects to the level of a few percent at SuperKEKB. The design of the mirror and its heat sink/holder will be presented, along with numerical simulations of the expected heat-induced mirror surface deformations will be presented.

INTRODUCTION

The synchrotron radiation monitors at SuperKEKB will use source bends in the same locations as at KEKB, which are the 5 mrad "weak bends" heading into the Fuji (LER) and Oho (HER) straight sections. The source bend parameters are shown in Table 1. The source bend for the LER will be replaced with one with a longer core and larger bending radius (a re-used LER regular arc bend magnet) in order to reduce the SR power intensity. Despite the reduced bending radius, the increase in beam energy and beam current means that the incident angular power density will be higher (72 W/mrad) than that of the KEKB LER (48 W/mrad). The source bend will remain the same at the HER, and the effect of the increased current of the beam is almost cancelled out by the reduced beam energy, so that the angular power density is only a little bit higher than at KEKB.

It is planned to move the chambers a bit further downstream from the source bends than they were at KEKB, which will help reduce the SR power intensity hitting the primary extraction mirrors. However, the heat deformation of the KEKB mirrors was already a very significant problem, requiring complicated measures to measure and compensate for the distortion in real time in order to correct the beam-current dependence on the measured beam size. For this reason, we are pursuing the design of mirrors made of diamond, which has a higher heat conductivity and lower thermal expansion coefficient than beryllium. The design of the mirror will be described in the next section.

Table 1: SR Source bend parameters

Parameter	KEKB		SuperKEKB	
	LER	HER	LER	HER
Energy (GeV)	3.5	8	4	7
Current (A)	2	1.4	3.6	2.6
Bending radius (m)	85.7	580	177.4	580
SR Power (W/mrad)	48	136	72	149

DESIGN

The design of the mirror is based on CVD diamond, made by Cornes Technology (formerly Seki Technotron) and EDP Corporation. For best thermal conductivity, the idea mirror material would be a pure monoctystalline diamond, rather than a polycrystalline one. The monocrystalline diamond also gives good surface smoothness after polishing, with an Ra from 2-10 nm expected. For optical reflectivity, a metallic surface is needed.

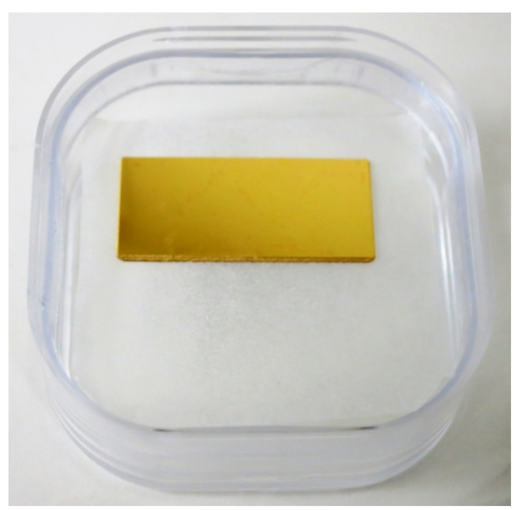

Figure 1: 10 mm x 20 mm x 0.65 mm prototype diamond mirror, consisting of two 10 mm x 10 mm monocrystals, with 3 μm Au reflective coating.

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The size of mirror we currently expect to need is ~10-20 mm wide x 30 mm tall; the prototypes manufactured for us so far consist of 10 mm x 10 mm monocrystalline sections fused together, with a reflective surface made of 3 um of gold. A 10 mm x 20 mm x 0.65 mm prototype is shown in Fig. 1.

Figure 2: Copper mirror mount.

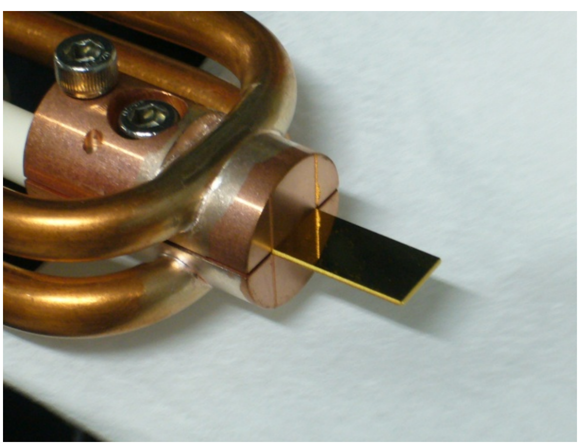

Figure 3: Copper mirror mount, with prototype mirror mounted in it.

The design of the holder presented some issues. ANSYS simulations (see below) showed that for any holder design which touches the mirror on all edges or along the back side, the deformation of the holder would be large enough to cause unacceptable deformations in the surface of the diamond mirror, much larger than the deformations caused by the heat distribution pattern in the diamond mirror itself. The solution that was finally settled on was a split cylinder of soft copper, which grips the mirror near one edge only. The soft copper permits a good heat-sinking contact with the portion of the mirror surface gripped within the split (about 6 mm), without placing any extraneous strain on the surface of the mirror due to heat deformation of the copper. Each half of the copper cylinder is cooled with symmetrically-located water pipes brazed in place. A prototype of the holder/heat sink made by Cornes Technology is shown in Fig. 2, and a prototype mirror mounted in the holder is shown in Fig. 3.

SIMULATIONS

ANSYS simulations were carried out to investigate the effect of a line heat source (such as from an SR fan) on the surface of a diamond mirror. The mirror was simulated as a 20 mm x 20 mm x 1 mm monocrystalline diamond with a 3 µm gold coating. The diamond is treated as having a heat transfer coefficient of 2000 W/k/m, and a thermal expansion coefficient of 2.6 µm/m/K. The mirror is mounted in a copper heat sink/holder of the same design as the prototype, and with the water in the cooling channels being treated as a constant-temperature heat sink.

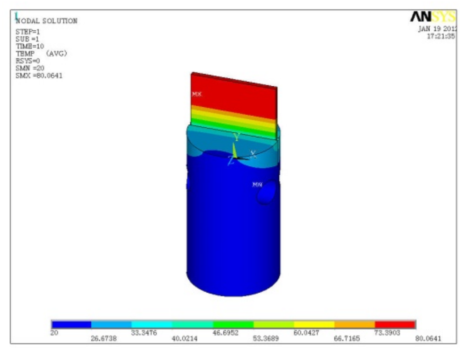

Figure 4: ANSYS simulation of temperature distribution of diamond mirror in copper holder, heated in a 2-mm horizontal ribbon on the mirror's face.

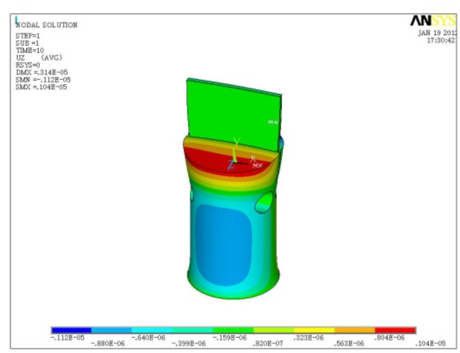

Figure 5: Shape deformation of simulated mirror and holder under heating. (Colors represent deformation in z-direction, perpendicular to mirror surface.)

The temperature distribution for 400 W applied over a 2-mm high ribbon across the 20-mm width of the diamond mirror is shown in Fig. 4. The resulting shape distortion is shown in Fig. 5, with the z-direction (perpendicular to mirror surface) distortions highlighted

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in color. A cross-section of the surface of the mirror is shown in Fig. 6. As can be seen, the surface of the mirror essentially "folds" back at the point of heating, with the part of the face above the heat ribbon (to the right in Fig. 6) is tilted away from the part below the ribbon (to the left in Fig. 6).

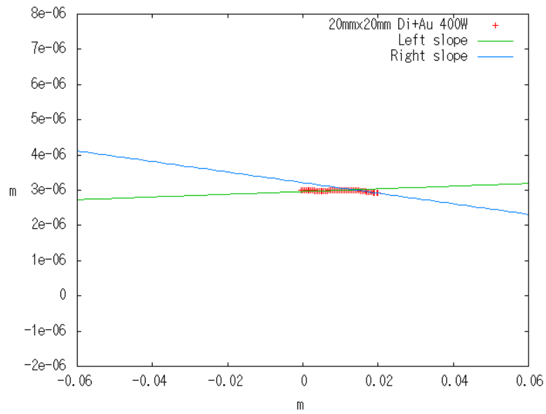

Figure 6: Surface deformation of 1-mm thick monocrystalline diamond mirror due to 400 W applied over 20 mm width of mirror.

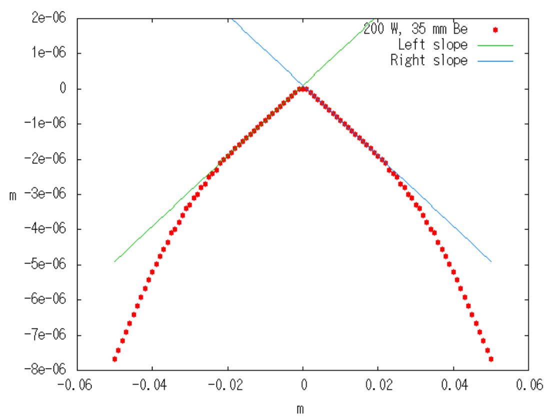

Figure 7: Surface deformation for Be mirror of type used at KEKB for 200 W applied over 35 mm width of mirror.

For comparison, the same surface distortion is shown for a Be mirror of the type used at KEKB (a 35 mm wide by 35 mm deep block of beryllium, mounted to a water-cooled copper heat sink on the back). While simulated power intensity is much lower for the beryllium block, it can be seen that the resulting surface deformation is much higher.

The mirror surface deformation has been found to scale roughly linearly with applied heat (see below). Scaling the results above to the power intensity expected at SuperKEKB, and accounting for the effect of mirror deformations on the effective slit separation for an interferometer, the deformation in the beryllium mirror is projected to cause a change of 43% in the measured beam size at full current in the HER. The diamond mirror, in comparison, would only change the apparent beam size by about 3%, which would represent a great improvement.

PROTOTYPE SIMULATIONS

The first prototype received is a 10 mm x 20 mm x 0.65 mm quasi-monocrystal, comprising two 10 mm x 10 mm sections fused together, which was polished on both sides but only coated with gold on the front side. The backside of the prototype mirror was uncoated. In planned measurements, an infrared line heater will be applied to the back side in order to leave the front side free from obstruction, so that the surface flatness can be measured. Simulations were made of the 10 mm x 20 mm x 0.65 mm diamond mirror prototype, for different amounts of absorbed heat. The heat source was treated as occurring in a 2 mm high by 10 mm wide (full width of prototype mirror) region, with 100 W, 200 W and 400 W being simulated. The resulting cross-sections of the surface across the heat source are shown in Fig. 8.

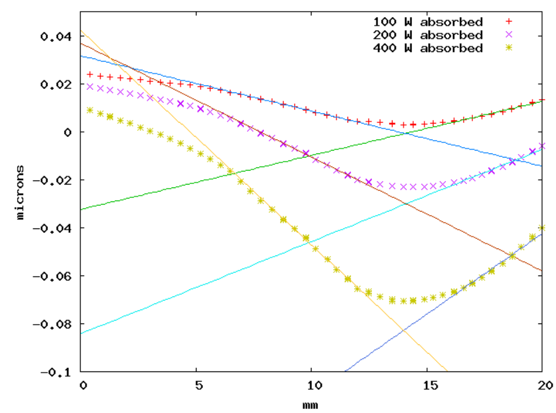

Figure 8: ANSYS simulation of the surface deformation of 10 mm x 20 mm x 0.65-mm monocrystalline diamond mirror at different absorbed heat loads.

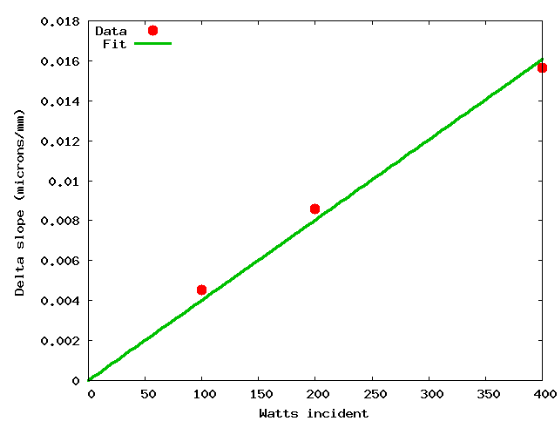

Figure 9: Differences in surface slope on either side of the heating line from ANSYS simulations in Fig. 8. The best fit slope difference is 4x10^{-5} µm/mm/W.

Figure 9 shows the differences in left-hand versus right-hand slope for different incident heat levels. The best-fit slope difference across the heat source line is 4x10^{-5} µm/mm/W, which is about half of the level seen in the simulation for the 20 mm x 20 mm x 1 mm mirror.

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Preliminary measurements were attempted on the prototype mirror using a Shack-Hartmann wavefront sensor (Thorlabs WFS-K2), a He-Ne laser, and using an infrared line heater (Fintech LHW-30) to provide a heat source for the mirror. Unfortunately, the precision of the measurement setup at present is not sufficient to measure changes in mirror surface of the order required to verify the simulation. Modifications will be made to improve the precision of the measurement setup, including a wider-field wavefront measurement system and a more powerful heat source, and be reported in a future paper.

SUMMARY AND FUTURE DIRECTIONS

We have designed a diamond extraction mirror and holder that, according to simulations, should suffer much less heat-induced surface deformation than the beryllium mirrors used at KEKB. The eventual size of mirror we need will be 10-20 mm wide by 30 mm tall by 1 mm thick. Initial prototypes have been made of monocrystalline fused tiles, which are undergoing testing to verify their performance. If necessary it is expected that tiled quasi-monocrystalline mirrors can be used at SuperKEKB, and eventually it is hoped that a single monocrystalline structure will become feasible. Current prototypes are coated with gold, but it is planned to try a nickel coating in the future.

ACKNOWLEDGMENT

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REFERENCES

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