MEDSI 2016 WEPE10

Mechanical Design of Pulse-by-pulse X-ray Beam Position Monitor using Diamond Heat Sink

SPring-8 2016/09/14

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Introduction

A conventional X-ray beam position monitor (XBPM) is photoemission type, and blade-shaped tungsten is used as detector heads to secure heat resistance. The conventional XBPM, however, cannot measure pulse-by-pulse beam position, because the time constant of the detector head is long due to the stray capacitance and the impedance is not matched to 50 Ω of cables. For the undulator beamlines, further improvement of heat-resistance is required.

Therefore, we are developing a pulse-by-pulse XBPM for undulator beamlines by introducing heat resistance structure that employed a diamond heat sink. We have designed the monitor aiming at improving heat-resistance property without degradation of high frequency property, and manufactured a prototype to evaluate a feasibility of the design.

Structure of Prototype

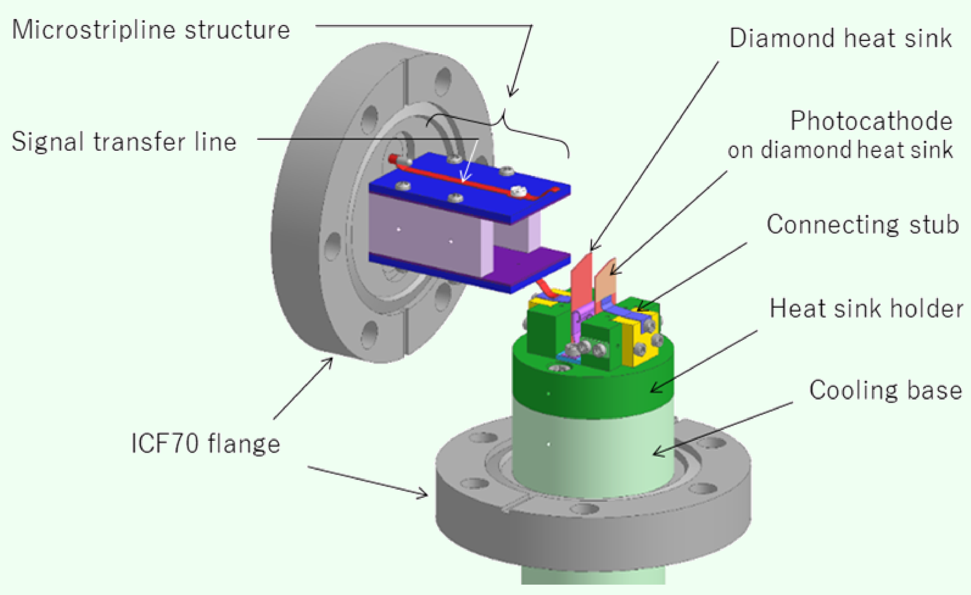


Figure 1: 3D image of the cooling structure (bottom) and the microstripline structure (left).

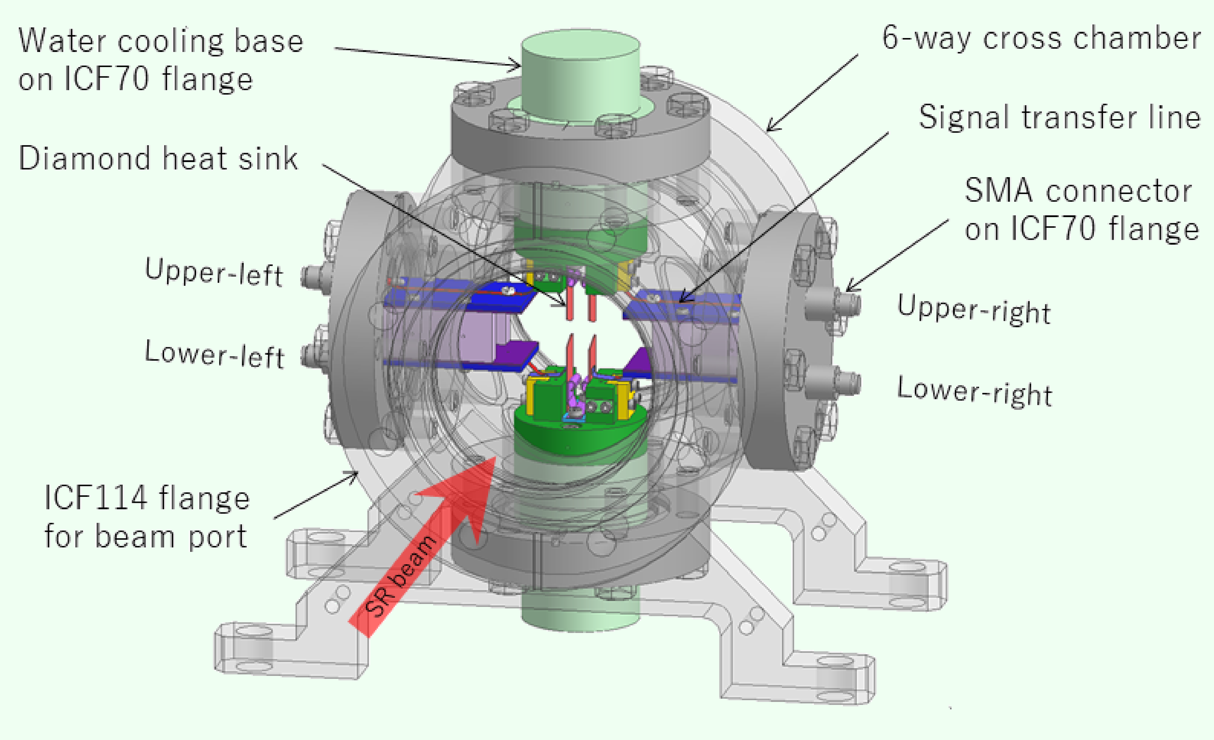


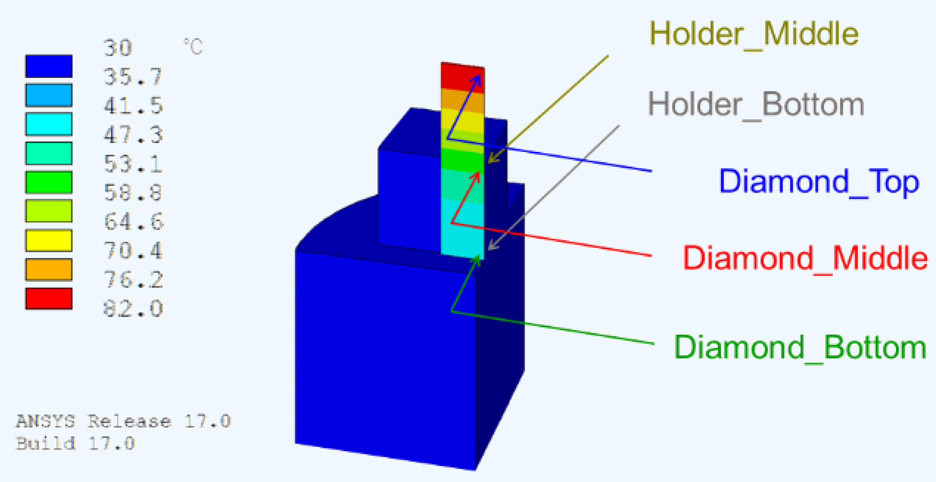
Figure 2: 3D image of the prototype.

An increase in time constant (t = RC) can be supressed by lowering the stray capacitance with securing an effective area of the photocathode, while accepting impedance mismatch around the photocathode

By separating signal transfer line from cooling mechanism, the heat-resistant property is expected to be improved.

A couple of DN40CF (ICF790) flanges equipped with the detector heads (the signal transfer lines) are mounted on the top/bottom (left/right) ports. Two beam ports are faced using DN63CF (ICF114) flanges with a face-to-face dimension of 120 mm.

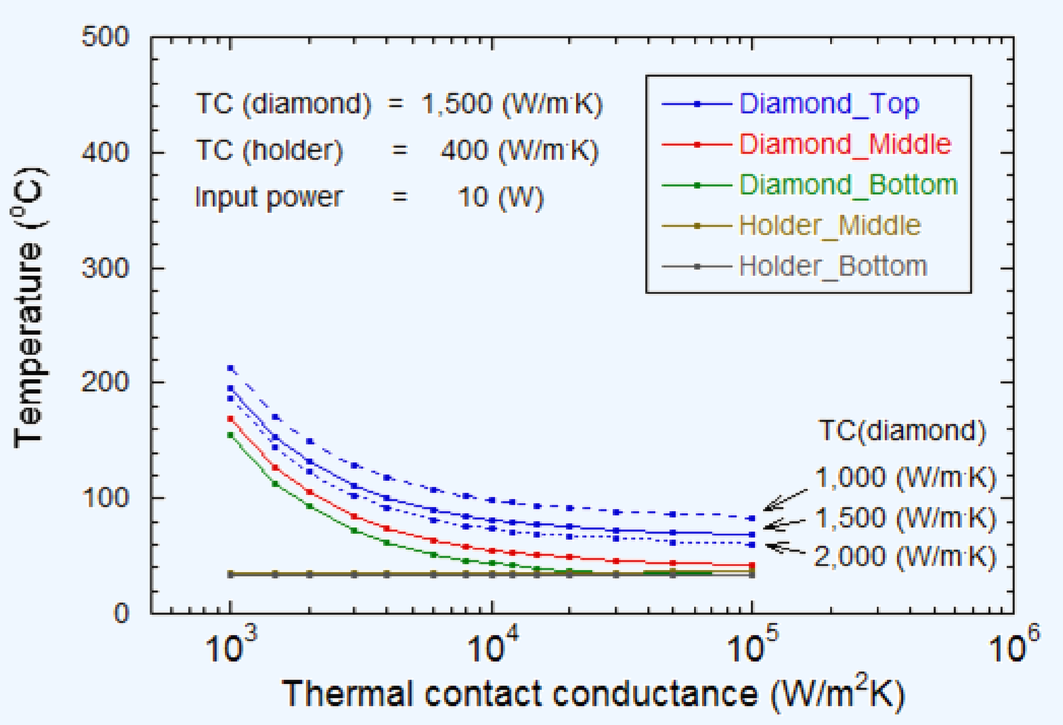
Thermal Finite Element Analysis



Thermal conductance (TC):
Diamond 1,500 W/(m·K)
Copper 400 W/(m·K)
Thermal contact conductance (TCC)
Diamond/Copper : 10,000W/(m²·K)
Total input power: 10W
on tip (1 × 8 × 0.3 mm) of the heat sink
Homoiothermal condition: 30° C
on bottom of the cooling base

Figure 3: Quarter model for FEM and the results. Arrows indicate locations of measuring points.

The analysis result of this representative model is within the tolerance, if the tolerance of the temperature rise is set as $\Delta t = 100$ K for a realistic value,



The temperature at each point on condition that the TC of the diamond is 1,500 W/(m·K) are plotted as a function of the TCC between the diamond sink and the copper.

This result suggests that the TCC is not so effective for heat-resistance property if the TCC exceeds 10,000 W/(m²·K), and that, on the other hand, the temperature rise exceeds the tolerance of 100 K if the TCC below 2,000 W/(m²·K).

Figure 4: Thermal contact conductance (TCC) dependence of temperature.

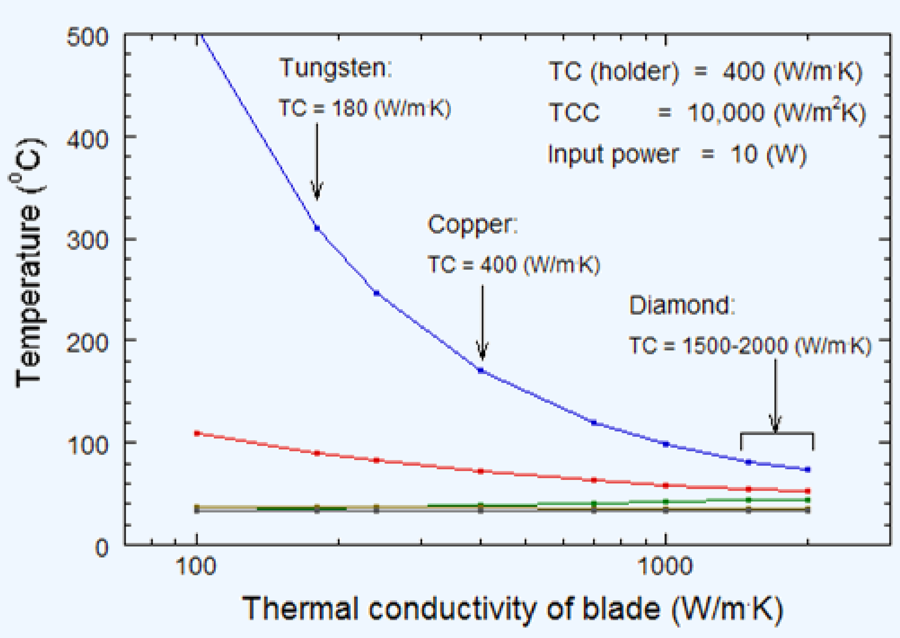


Figure 5: Thermal conductivity (TC) dependence of temperature.

If the TC of diamond is higher than 1,500 W/(m·K), the temperature rise is suppressed reasonably, and it is not required to know the exact number of the TC of diamond.

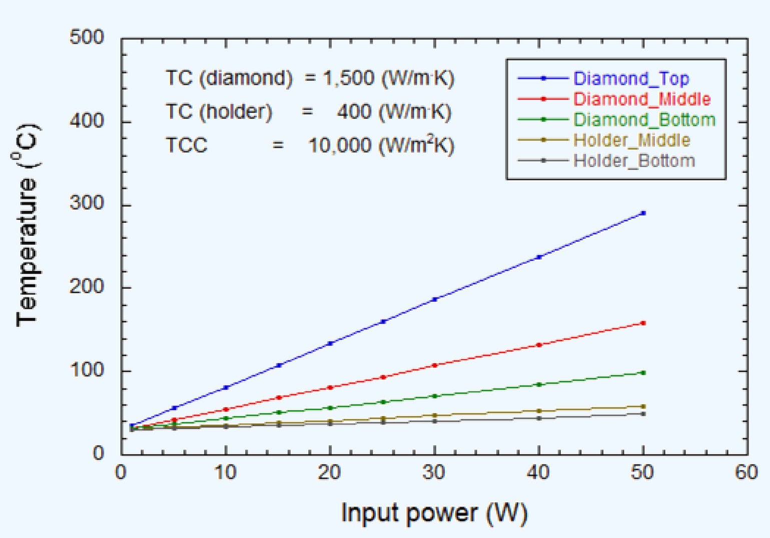


Figure 6: Input power dependence of temperature.

The maximum input power reaches around 25W during commissioning/tuning of beamlines.

This calculation shows that the current design is practicable.

Time-domain Reflectometry (TDR)

A time-domain reflectometry (TDR) by using a single input pulse was utilized to evaluate high frequency property of this monitor. An input signal is an isolated single pulse with unipolar (140 ps FWHM).

The actual role of this monitor is to propagate an impulse from a tip of the detector head to the measuring instrument through the signal transfer line. Therefore, it is possible to predict a time structure of an actual output signal by observing the isolated single pulse that is input directly from the detector head through a probe, namely, a time-domain transmissometry (TDT). We discuss about the results using TDR, because it has been already confirmed that the results from TDR resembles those from TDT.

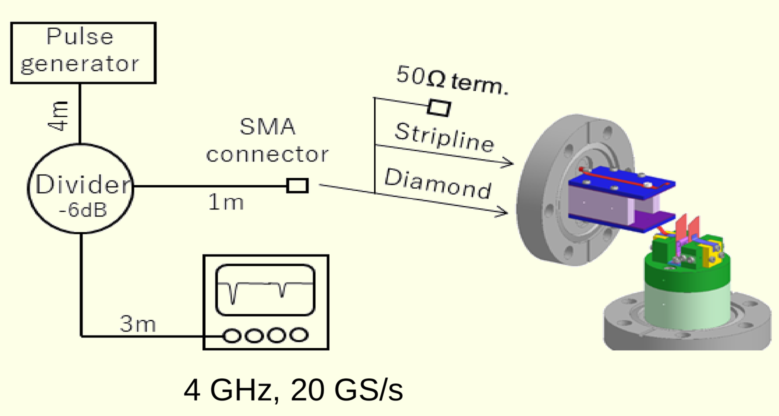


Figure 7: Experimental setup for the time-domain reflectometry.

The reflected signal makes a round trip along the cable (1m), and about 10ns later it is observed with the oscilloscope.

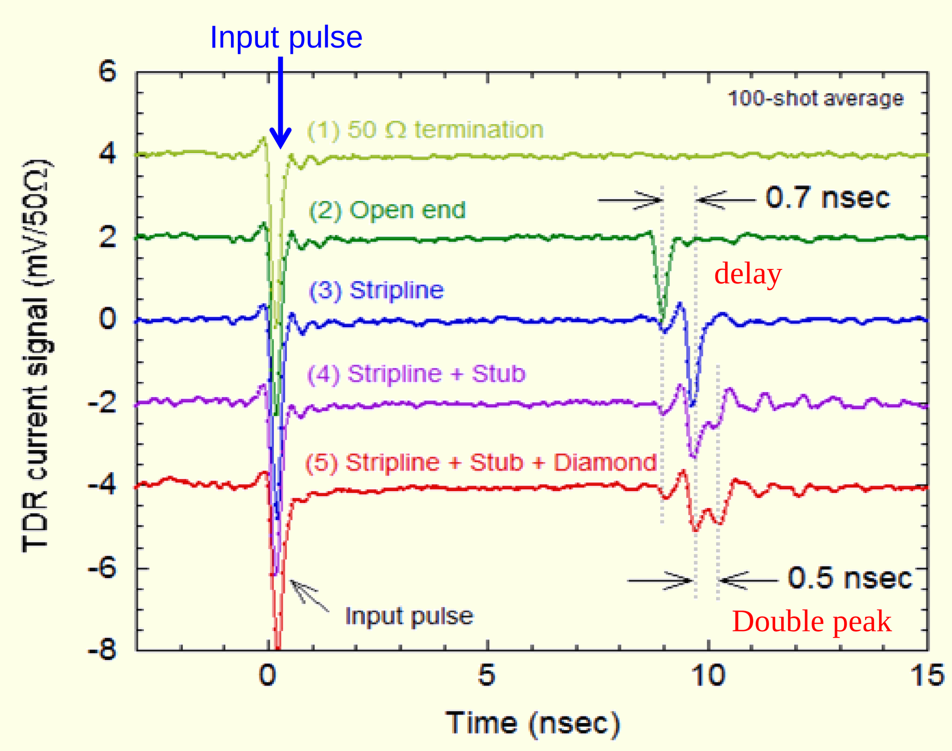


Figure 8: Experimental results of Time-domain reflectometry.

The double peak is the result of impedance mismatching of the section between the microstripline structure and the electrode on the diamond heat sink.

To consider the relation between the results obtained by TDR and the waveform generated actually from a monitor, three kinds of diamond device were compared.

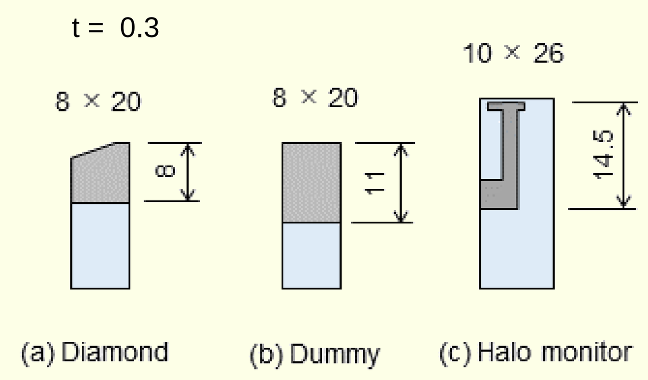


Figure 9: Structure of heat sinks and a diamond detector. Shaded areas are electrodes.

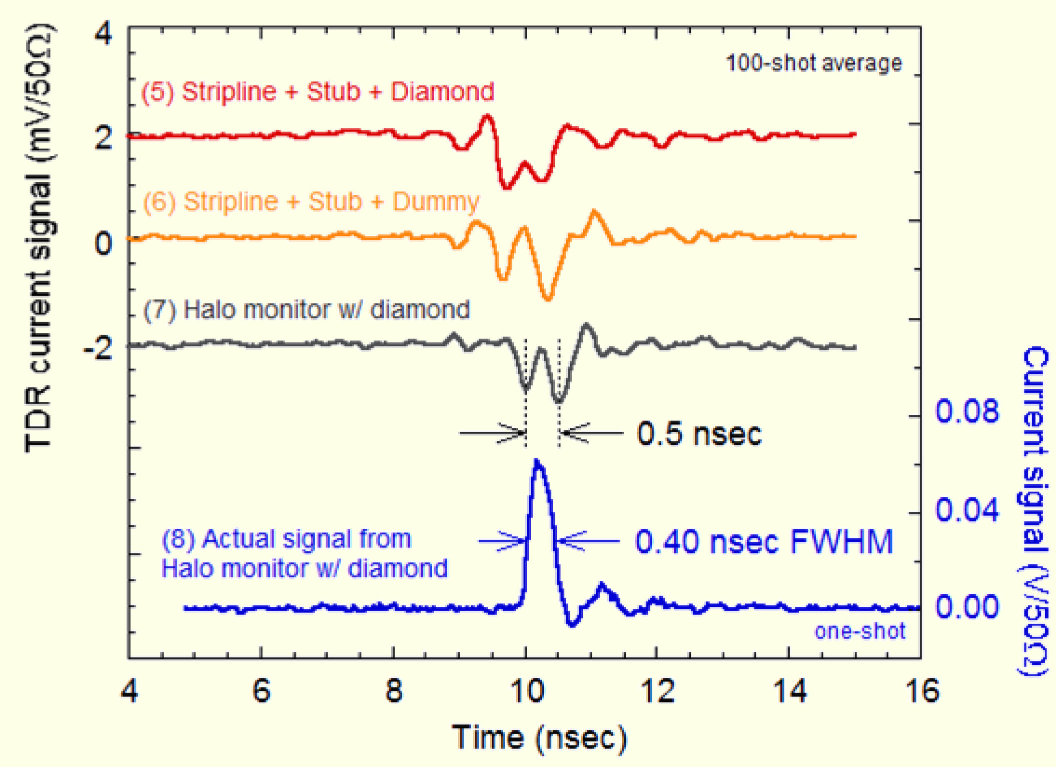


Figure 10: Comparison of the results of time-domain reflectometry with an actual pulse shape of the halo monitor.

The pulse length of the actual pulse (blue) is 0.4 ns FWHM, while the width of the double peak (black) seen in TDR of (c) is 0.5 ns.

These results suggest that this monitor generates the unipolar pulse signal with the pulse length of sub-nanosecond.

Summary

We have designed the pulse-by-pulse X-ray beam position monitor using the diamond heat sink, and manufactured the prototype to evaluate the thermal and high frequency properties. The results of thermal finite element analyses suggest that the diamond heat sink mounted on the holder described here is practicable from the heat-resistant point of view, if the TCC between diamond and copper is assumed to be 10,000 W/(m²·K). The evaluation tests of the prototype on high frequency property using TDR suggest that the single isolation pulse of the sub-nanosecond can be provided.