

chemical mechanical polishing (CMP), wet chemical etching, electrochemical etching, or dry plasma etching so that the top portion of the CNT array is exposed, with the bottom part remaining embedded in the filler materials; and (4) the embedded CNT array is applied against an object that is to be cooled. CNTs can reversibly buckle or bend one-by-one under low loading pressure so that a CNT can make maximum contact

with the object to be cooled, even an object with a very rough surface.

Heat can be effectively transferred from the contacting spots along the tube axis to the filler materials as well as the substrates. The filler materials play two critical roles: improving the mechanical stability and maximizing the thermal conductivity. Choosing highly thermal conductive materials as the filler matrix maximizes the heat transfer from the contact spots to the

substrate (i.e., the heat sink or cooling reservoir). An embedded CNT array can be reused without damage or compromise of its heat transport characteristics, in contrast to an approach that relies upon eutectic bonding.

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## Composite Laminate With Coefficient of Thermal Expansion Matching D263 Glass

**The laminate is a combination of carbon fiber with fiberglass.**

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The International X-ray Observatory project seeks to make an X-ray telescope assembly with 14,000 flexible glass segments. The glass used is commercially available SCHOTT D263 glass. Thermal expansion causes the mirror to distort out of alignment. A housing material is needed that has a matching coefficient of thermal expansion (CTE) so that when temperatures change in the X-ray mirror assembly, the glass and housing pieces expand equally, thus reducing or eliminating distortion. Desirable characteristics of this material include a high stiffness/weight ratio, and low density.

Some metal alloys show promise in matching the CTE of D263 glass, but their density is high compared to aluminum, and their stiffness/weight ratio is not favorable. A laminate made from carbon fiber reinforced plastic (CFRP) should provide more favorable

characteristics, but there has not been any made with the CTE matching D263 Glass.

It is common to create CFRP laminates of various CTEs by stacking layers of "prepreg" material at various angles. However, the CTE of D263 glass is 6.3 ppm/°C at 20 °C, which is quite high, and actually unachievable solely with carbon fiber and resin.

A composite laminate has been developed that has a coefficient of thermal expansion identical to that of SCHOTT D263 glass. The laminate is made of a combination of T300 carbon fiber, E-glass, and RS3C resin. The laminate has 50% uni-T300 plies and 50% uni-E-glass plies, with each fiber-layer type laid up in a quasi-isotropic laminate for a total of 16 plies. The fiber volume (percent of fiber compared to the resin) controls the CTE to a great extent. Tests have con-

firmed that a fiber volume around 48% gives a CTE of 6.3 ppm/°C. This is a fairly simple composite laminate, following well established industry procedures.

The unique feature of this laminate is a somewhat unusual combination of carbon fiber with E-glass (fiberglass). The advantage is that the resulting CTE comes out to 6.3 ppm/°C at 20 °C, which matches D263 glass. The trick with this laminate is to establish the proper fiber volume to get the desired CTE. Laminates were made with several different fiber volumes and coupons were tested to establish the relationship between fiber volume and CTE. Testing proved that fiber volume should be about 48%.

*This work was done by David Robinson and Benjamin Rodini of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16261-1*