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Addendum: "Reduction in thermal boundary conductance due to proton implantation in silicon and sapphire" [Appl. Phys. Lett. 98, 231901 (2011)]

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In our recent work,[1] we observed a reduction in thermal boundary conductance at Al/Si and Al/sapphire interfaces when the Si and sapphire substrates were subjected to ion irradiation prior to Al metallization. We hypothesized that this reduction was due to ion-induced bond breaking and reformation near the interface leading to damage and amorphization of the crystalline substrate surface.

Additional analysis of the samples revealed a third mechanism capable of producing a dose-dependent thermal boundary conductance under the current data analysis method: a thin amorphous carbonaceous layer formed on the substrate during the implantation process. Transmission electron microscopy showed a carbon layer thickness ranging from 4 to 38 nm, with the thickness increasing with ion dose, which was speculated to be an artifact of contamination from the vacuum pumps in the ion implanter. Follow-up work showed that removing oil-containing components from the implanter vacuum system did not eliminate this layer, implying that a post-implantation plasma cleaning is required to remove the confounding effects of carbon in this type of study.

Despite the discovery of this carbon layer at the interface and the associated mechanism developed, we still cannot conclusively pinpoint the precise origin of the reduction in thermal boundary conductance due to ion irradiation. Our inability to fully explain the experimental trends with surface and sub-surface structural and chemical defects and amorphous carbon formation alone leads us to believe that there are yet-undiscovered mechanisms contributing to the reduction in thermal boundary conductance at Al/Si and Al/sapphire interfaces due to ion irradiation. We are currently pursuing additional experimental studies to fully elucidate these mechanisms.

We greatly appreciate Professor D. G. Cahill at the University of Illinois at Urbana-Champaign for raising the question of whether carbon deposition during ion irradiation could be affecting the results.

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[1] P. E. Hopkins, K. Hattar, T. Beechem, J. F. Ihlefeld, D. L. Medlin, and E. S. Piekos, Appl. Phys. Lett. **98**, 231901 (2011).

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