Waals and/or hydrogen bonding between a carrier and a thin glass sheet, but a covalent bonding area is still used as well. Thus, although the articles and methods for processing thin sheets with carriers in US '727 and US '880 are able to withstand the harsh environments of FPD processing, undesirably for some applications, reuse of the carrier is prevented by the strong covalent bond between thin glass and glass carrier in the bonding region that is bonded by covalent, for example Si-O-Si, bonding with adhesive force ~1000-2000 $mJ/m^2$, on the order of the fracture strength of the glass. Prying or peeling cannot be used to separate the covalently bonded portion of the thin glass from the carrier and, thus, the entire thin sheet cannot be removed from the carrier. Instead, the non-bonded areas with the devices thereon are scribed and extracted leaving a bonded periphery of the thin glass sheet on the carrier.

## SUMMARY

**[0013]** In light of the above, there is a need for a thin sheet – carrier article that can withstand the rigors of the FPD processing, including high temperature processing (without outgassing that would be incompatible with the semiconductor or display making processes in which it will be used), yet allow the entire area of the thin sheet to be removed (either all at once, or in sections) from the carrier so as to allow the reuse of the carrier for processing another thin sheet. The present specification describes ways to control the adhesion between the carrier and thin sheet to create a temporary bond sufficiently strong to survive FPD processing (including LTPS processing) but weak enough to permit debonding of the sheet from the carrier, even after high-temperature processing. Such controlled bonding can be utilized to create an article having a re-usable carrier, or alternately an article having patterned areas of controlled bonding and covalent bonding between a carrier and a sheet. More specifically, the present disclosure provides surface modification layers (including various materials and associated surface heat treatments), that may be provided on the thin sheet, the carrier, or both, to control both room-temperature van der Waals, and/or hydrogen, bonding and high temperature covalent bonding between the thin sheet and carrier. Even more specifically, the room-temperature bonding may be controlled so as to be sufficient to hold the thin sheet and carrier together during vacuum processing, wet processing, and/or ultrasonic cleaning processing. And at the same time, the high temperature covalent bonding may be controlled so as to prevent a permanent bond between the thin sheet and carrier during high temperature processing, as well as maintain a sufficient bond to prevent delamination during high temperature processing. In alternative examples, the surface modification layers may be used to create various controlled bonding areas (wherein the carrier and sheet remain sufficiently bonded through various processes, including vacuum

processing, wet processing, and/or ultrasonic cleaning processing), together with covalent bonding regions to provide for further processing options, for example, maintaining hermeticity between the carrier and sheet even after dicing the article into smaller pieces for additional device processing. Still further, some surface modification layers provide control of the bonding between the carrier and sheet while, at the same time, reduce outgassing emissions during the harsh conditions in an FPD (for example LTPS) processing environment, including high temperature and/or vacuum processing, for example.

**[0013a]** In one aspect, the present disclosure relates to a method of annealing glass, comprising stacking a plurality of glass layers, each of the glass layers having two major surfaces, so that interfaces are defined between adjacent ones of the glass layers in the plurality of glass layers, wherein there is disposed on at least one of the major surfaces that faces one of the interfaces, a surface modification layer; exposing the stack of glass layers to a time-temperature cycle sufficient to compact each of the glass layers, wherein the surface modification layer is sufficient to control, throughout the time-temperature cycle, bonding between the adjacent ones of the glass layers in the stack defining the one of the interfaces, wherein bonding is controlled to be of such a force so that one layer does not separate from another if one is held and the other subjected to the force of gravity, but so that the layers may be separated without breaking one of the adjacent ones of the glass layers into two or more pieces.

**[0014]** Additional features and advantages will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from the description or recognized by practicing the various examples as exemplified in the written description and the appended drawings. It is to be understood that both the foregoing general description and the following detailed description are merely exemplary of the various examples, and are intended to provide an overview or framework to understanding the nature and character of the disclosure as it is claimed.

**[0015]** The accompanying drawings are included to provide a further understanding of principles of the disclosure, and are incorporated in and constitute a part of this specification. The drawings illustrate one or more example(s), and together with the description serve to explain, by way of example, principles and operation of the disclosure. It is to be understood that various features disclosed in this specification and in the drawings can be used in any and all combinations. By way of non-limiting example the various features may be combined with one another as set forth in the appended claims

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0016]** FIG. 1 is a schematic side view of an article having carrier bonded to a thin sheet with a surface modification layer therebetween.

**[0017]** FIG. 2 is an exploded and partially cut-away view of the article in FIG. 1.

**[0018]** FIG. 3 is a graph of surface hydroxyl concentration on silica as a function of temperature.

**[0019]** FIG. 4 is a graph of the surface energy of an SC1-cleaned sheet of glass as a function annealing temperature.

**[0020]** FIG. 5 is a graph of the surface energy of a thin fluoropolymer film deposited on a sheet of glass as a function of the percentage of one of the constituent materials from which the film was made.

**[0021]** FIG. 6 is a schematic top view of a thin sheet bonded to a carrier by bonding areas.

**[0022]** FIG. 7 is a schematic side view of a stack of glass sheets