Claims

1. A method for densifying a thermoplastic film on a substrate, comprising:

depositing a thermoplastic in soluble form onto the substrate to form a film, wherein the thermoplastic has a convection oven cure of 350ºC to 400ºC;

soft baking the film to remove residual solvent; and,

curing the film by variable frequency microwave, VFM, for 20 to 120 minutes at a temperature at least 100ºC below the glass transition temperature, T_g, of the thermoplastic, and at least below a temperature of about 250ºC, said curing conducted until the coefficient of thermal expansion of the film sufficiently matches that of the substrate to reduce warpage of the film-substrate combination.

2. The method of claim 1, wherein the thermoplastic comprises a polyimide having a di-functional polyamic acid section and a di-functional amine section, and the polyimide has a T_g in the range of 300-400ºC.

3. The method of claim 2, wherein the polyimide comprises 3,3',4,4'-biphenyltetracarboxylic acid dianhydride-p-phenylenediamine (BPDA-PPD) and the VFM curing is carried out at a temperature of about 175-225ºC.

4. The method of claim 1, wherein the VFM curing comprises applying microwave power in a sweeping manner over a bandwidth of at least $\pm$5% of a selected center frequency.

5. The method of claim 1, wherein the substrate comprises a semiconductor wafer having integrated circuits thereon.

6. The method of claim 1, wherein the thermoplastic comprises a polymer selected from the group consisting of: polyimides, polyolefins, polyvinyls, polycarbonates, and acrylonitriles.

7. The method of claim 6, further comprising reducing the polydispersity index (PDI) of the thermoplastic in soluble form.

8. The method of claim 7, wherein the PDI is reduced by using separation techniques including size exclusion chromatography or by limiting initialization of a thermoplastic endcap reaction during formation of starting materials for the thermoplastic.

9. A method for making a microelectronic device, comprising:

preparing a semiconductor wafer with an integrated circuit thereon, wherein the integrated circuit is a memory device;

depositing a thermoplastic in soluble form onto the semiconductor wafer to form a film;

soft baking the film to remove residual solvent; and,

curing the film by VFM for 20 to 120 minutes at a temperature at least 100^{o}C below the glass transition temperature, T_g, of the thermoplastic, said curing conducted until the coefficient of thermal expansion of the film sufficiently matches that of the semiconductor wafer to reduce warpage of the film-wafer combination.

10. The method of claim 9, wherein the thermoplastic comprises a polyimide having a di-functional polyamic acid section and a di-functional amine section, and the polyimide has a T_g in the range of 300-400^{o}C.

11. The method of claim 10, wherein the polyimide comprises 3,3',4,4'-biphenyltetracarboxylic acid dianhydride-p-phenylenediamine (BPDA-PPD) and the VFM curing is carried out at a temperature of about 175-225^{o}C.

12. The method of claim 9, wherein the VFM curing comprises applying microwave power in a sweeping manner over a bandwidth of at least ±5% of a selected center frequency.

13. The method of claim 9, wherein the integrated circuit comprises functional circuit features from 100 to 10 nm in width and the thermoplastic has a T_g in the range of 300-400^{o}C.

14. The method of claim 1, wherein curing the film comprises curing the film for 60 to 120 minutes at a temperature at least 100^{o}C below the glass transition temperature, T_g, of the thermoplastic.

15. The method of claim 1, wherein curing the film comprises curing the film for 60 to 75 minutes at a temperature at least 100^{o}C below the glass transition temperature, T_g, of the thermoplastic.

16. A method for making a microelectronic device, comprising:

preparing a semiconductor wafer with an integrated circuit thereon;

performing a plurality of packaging process steps on the semiconductor wafer with the integrated circuit;

subsequently depositing a thermoplastic in soluble form onto the semiconductor wafer to form a film;

soft baking the film to remove residual solvent; and

curing the film by variable frequency microwave, VFM, for 20 to 120 minutes at a curing temperature at least 100^{o}C below the glass transition temperature, T_g, of the thermoplastic, said curing conducted until the coefficient of thermal expansion of the film sufficiently matches that of the semiconductor wafer to reduce warpage of the film-wafer combination, wherein a difference between the curing temperature and a maximum temperature of the plurality of packaging process steps is 50^{o}C or less.

17. The method of claim 9, wherein the integrated circuit has an upper temperature limit of 250^{o}C.

18. The method of claim 9, wherein the integrated circuit comprises functional circuit features in the range of 100 to 10 nm in width.

19. The method of claim 16, wherein the plurality of packaging process steps includes die attach, die encapsulation, molding, die underfill, or die stacking.

20. The method of claim 1, wherein the substrate is a semiconductor wafer with an integrated circuit thereon, and further comprising performing a plurality of packaging process steps on the semiconductor wafer with the integrated circuit prior to depositing a thermoplastic in soluble form onto the semiconductor wafer to form a film.

21. The method of claim 20, wherein the plurality of packaging process steps includes die attach, die encapsulation, molding, die underfill, or die stacking.

22. The method of claim 16, wherein the thermoplastic comprises a polyimide.