Advanced Low-k Polymer Dielectrics Platform for RF Applications

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Abstract

In this paper, properties as well as processability of our new class of low-k dielectric material platform based on fluorinated polymer technology is presented and this low-k material shows suitability to passivation and interlayer dielectrics for high performance compound semiconductor devices.

INTRODUCTION

Thermostable polymer dielectrics such as polyimides and BCB are widely used in compound semiconductor industry as passivation and interlayer dielectrics. In general, thermostable polymers have difficulty to lower their k value because of their aromatic hydrocarbon backbone structure and polar imide moiety of polyimides. Fluorinated polymers such as PTFE, PFA, FEP have excellent electrical properties, low water uptake, and high chemical durability, and are useful for many applications in industry. These fluorinated polymers that belong to a category of crystalline polymers are opaque due to scattering and insoluble in any solvent. New fluorinated polymer dielectrics are developed and properties and applications are discussed in the view of processability of this polymer.

PROPERTIES

Our material platform contains "CYTOP"[1] and "PSI polymer"[2] whose properties are shown in Table 1. CYTOP has the ring structure in the main chain and the ring structure gives this polymer amorphous morphology. The amorphous morphology of CYTOP adds required properties such as transparency and solubility in solvents for materials used in optical and electronics applications. PSI polymer has three structural features that are fluorinated rigid backbone structure, three dimensional molecular structure and high crosslinking density. CYTOP has the lowest k value and PSI polymer satisfies thermal, mechanical and electric requirements.

TABLE 1
PROPERTIES OF PSI POLYMER AND OTHER DIELECTRICS

	CYTOP	***PSI polymer***	**BCB**	**Polyimide**
<Electrical>				
k@1MHz	*2.1*	*2.4-2.5*	2.7	3.2-3.5
tanδ@1MHz	*<0.001*	*0.001*	0.001	0.02
<Thermo Mechanical>				
Tg (C)	*108*	*>350*	>350	>350
CTE (ppm)	*74*	*66*	65	10-80
<Processability>				
Solvent	*Fluorinated Chemicals*	*CV (cy.)*	CV (MES)	CV (NMP)
Curing Temp. (C)	*<250*	*250-350*	210-250	>350
Water Abs. (%)	*<0.1*	*0.23*	0.24	0.5-3
Adhesion	*Excellent*	*Excellent*		
Etching	*Dry etch*	*Dry etch*	Dry etch	Dry etch

CV: conventional cy.: cyclohexanone MES: mesitylene

PROCESSABILITY OF PSI POLYMER

A. Solubility and Thin Film Formation

The uncured polymer can be dissolved in conventional solvents such as cyclohexanone. Uniform thin films can be easily obtained from polymer solutions by spin-on technique followed by thermal curing (for 0.5-2hrs at 250-350C). Coatings in thickness from submicron up to 10 micron or more can be made by varying the solids fraction.

B. Etching capacity

PSI polymer film can be easily etched with simple oxygen plasma utilizing reactive ion etching (RIE) technique. Figure 1 shows a SEM cross section after etching followed by striping photo resist.

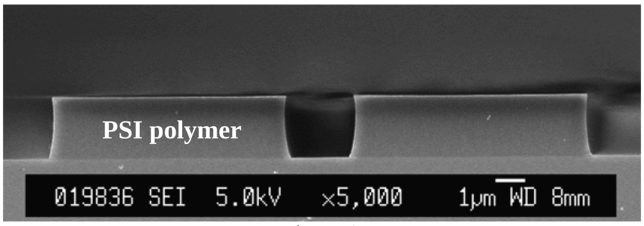


Figure 1
PSI FILM ETCHED WITH O2 PLASMA

C. Adhesion Property and Multilayer Stack

Adhesion Properties were evaluated with “Scotch Tape Test” onto Si and SiN substrates and the results are shown in Table 2. A pre-treatment with adhesion promoter is recommended for PSI-004 to ensure enough adhesion onto Si and SiN. PSI-005AP shows excellent adhesion properties without any pretreatment.

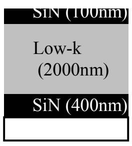
TABLE 2
ADHESION ONTO SI AND SIN

substrates	Si	SiN	Si Treated with AP	SiN Treated with AP
<PSI-004>				
As depo.	100	100	100	100
After PCT	0	0	100	100
<PSI-005AP>				
As depo.	100	100	-	-
After PCT	100	100	-	-

Test method: Scotch Tape Test based on JIS D0202.
The values are the % of area remained without any peeling.
PCT: Tested after Pressure-Cooker Test (121C, 2atm, 10hrs).

Figure 2 shows the test structure to evaluate adhesion properties to the upper layer. The surface of the polymer film was lightly ashed with various conditions prior to deposition of the upper nitride. Table 3 shows results of adhesion tests. Some delaminations were observed at the interface between the polymer and the upper nitride after PCT when no surface treatment was carried out (test 1). In the case of SF6 plasma as a surface treatment, severe delamination after PCT was observed. It may due to deposition of fluorinated materials during plasma process (test 2). Excellent adhesion was obtained when a surface treatment is carried out with oxygen plasma (test 3). These results tell us the surface property of the polymer can be controlled and the adhesion between the polymer film and the upper layer such as SiN can be improved by a surface treatment with appropriate conditions

Test structure



Process

▽400nm SiN depo.($SiH_4/NH_3/N_2$, 300C) on Si wafer
▽AP depo. followed by 2000nm low-k depo.
▽*Surface treatments with various conditions*
▽100nm SiN depo.

Figure 2
TEST STRUCTURE OF THE ADHESION PROPERTIES TO THE UPPER LAYER

TABLE 3
EFFECT OF THE SURFACE TREATMENT ON THE UPPER LAYER

Test #	Low-k surface treatment	Scotch Tape Test		Contact angle of water (deg)
		as depo.	aft. PCT	
1	None	100	90	85.4
2	SF6 plasma	100	9	105.3
3	O2 plasma	100	100	4.1

Test method: Scotch Tape Test based on JIS D0202.
The values are the % of area remained without any peeling.
PCT: Tested after Pressure-Cooker Test (121C, 2atm, 10hrs).

Figure 3 shows the SEM cross section of a multilayer stack with p-CVD SiN. 2000nm thick PSI-005AP with oxygen plasma surface treatment and 150nm thick nitride were multi-stacked. PSI polymer shows excellent adhesion onto under-layer as well as to upper-layer and the stack do not show any crack.

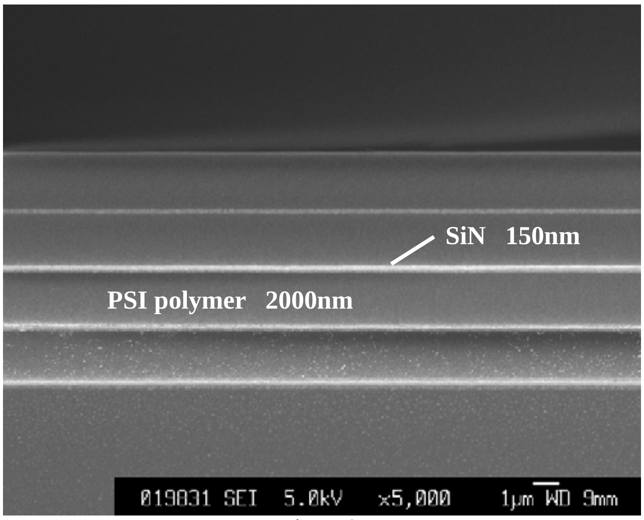


Figure 3
MULTILAYER STACK WITH SIN

C. Planarization Characteristics

One of essential requirements to dielectric layer is to planarize the underlying topography. The cured film of PSI polymer shows excellent planarization properties as shown in Figure 4 and Figure 5.

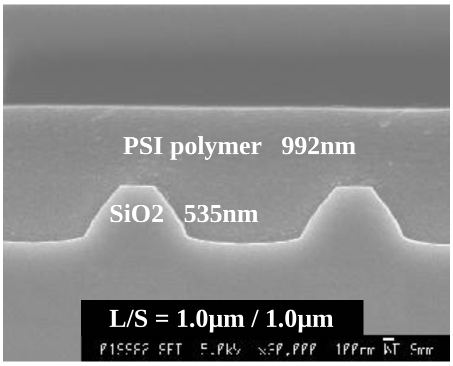


Figure 4
PLANARIZATION CHARACTERISTICS

Figure 5
PLANARIZATION CHARACTERISTICS

CONCLUSIONS

We have developed a new class of low-k dielectric material platform based on fluorinated polymer technology. These materials have k values ranging 2.1 to 2.5. We demonstrated the processability such as etching, adhesion, stacking and planarization capability of our thermally stable fluorinated material, PSI polymer. These excellent processabilities as well as electric properties apply this polymer to low-k dielectrics for advanced microwave and RF devices that have high density interconnect structures to contribute to improving device performance and reducing manufacturing costs.

REFERENCES

[1] S. Yokotsuka, et al, *Fluoropolymer 2000 Proceedings/PP* **2000**, 29.

[2] M. Ito, et al, *IEEE CPMT TC-6 Small Workshop in conjunction with 54th ECTC,* **2004**.