J Electroceram (2009) 23:141–145
DOI 10.1007/s10832-007-9340-y

Filler effect of low loss dielectricity in printed circuit board material

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Received: 30 May 2007 / Accepted: 2 October 2007 / Published online: 16 October 2007

Abstract Dielectric properties of low-loss dielectric materials are investigated with variation of silica filler which is known to be general filler in PCB composite. With comparison of dielectric losses of various filler materials in use of BCB resin, it could be known that crystalline cristobalite was superior to other crystalline or amorphous silica-base materials and reduced dielectric losses in the composite with resin. And dielectric properties of composite with the variation of filler quantity showed that amorphous silica and quartz increased dielectric loss as their quantities increased, while cristobalite increased little. As quantity of crystalline cristobalite phase increases in cristobalite/quartz intermediates, dissipation factor decreases.

Keywords Filler · Low loss dielectric · PCB

1 Introduction

Recently, both miniaturization and multifunctionality of electronic devices require high-valued electronic modules for use. Printed circuit board (PCB in the following), general substrate material, has important role in electronic module market, for many electronic chips are mounted on it and then it forms circuit module. PCB is composed of conducting circuits and insulating materials, and supports all electronic devices. As electronic modules are increasingly used in the range of microwave-frequencies and as signal rates increase, the most important requirement for PCB materials becomes low dielectric constant with low loss, due to low energy loss lead by low dielectric loss in substrate. Therefore, improvement of low-loss property in PCB material could be indispensably competitive advancement in electronic module market, compared to LTCC module [1–5]. However, resin, which composes PCB composite, has high-loss property, in general, owing to its main component of epoxy. Dielectric property of filler material is expected to be significant for PCB composite but has rarely been investigated till now, though that of PCB composite is thought to be dominated by resin. Especially, evaluating and comparing method of dielectric loss property is much less investigated, and loss property of silica, which is common filler for PCB composite, with its crystalline phase is rarely reported, either.

In this study, the effect of the filler on the dielectric loss property of PCB is sought with change of the crystalline phase of filler SiO_2, which is common for PCB, and the validity of that SiO_2, as low loss filler, is also examined. Moreover, the dielectric properties of PCB composite are observed with variation of filler amount.

2 Experimental procedure

As raw materials, oxides such as SiO_2, MgO (Kojundo chemical, Japan), and CaO (Kojundo chemical, Japan) were used. For SiO_2, two kinds of silica powder, amorphous (Sukgyung A.T., SG-1200, Korea) and quartz (Kojundo chemical, Japan), were used, and cristobalite phase was obtained from amorphous powder with heat treatment, as identified by XRD shown in Fig. 1(d). Basic properties of

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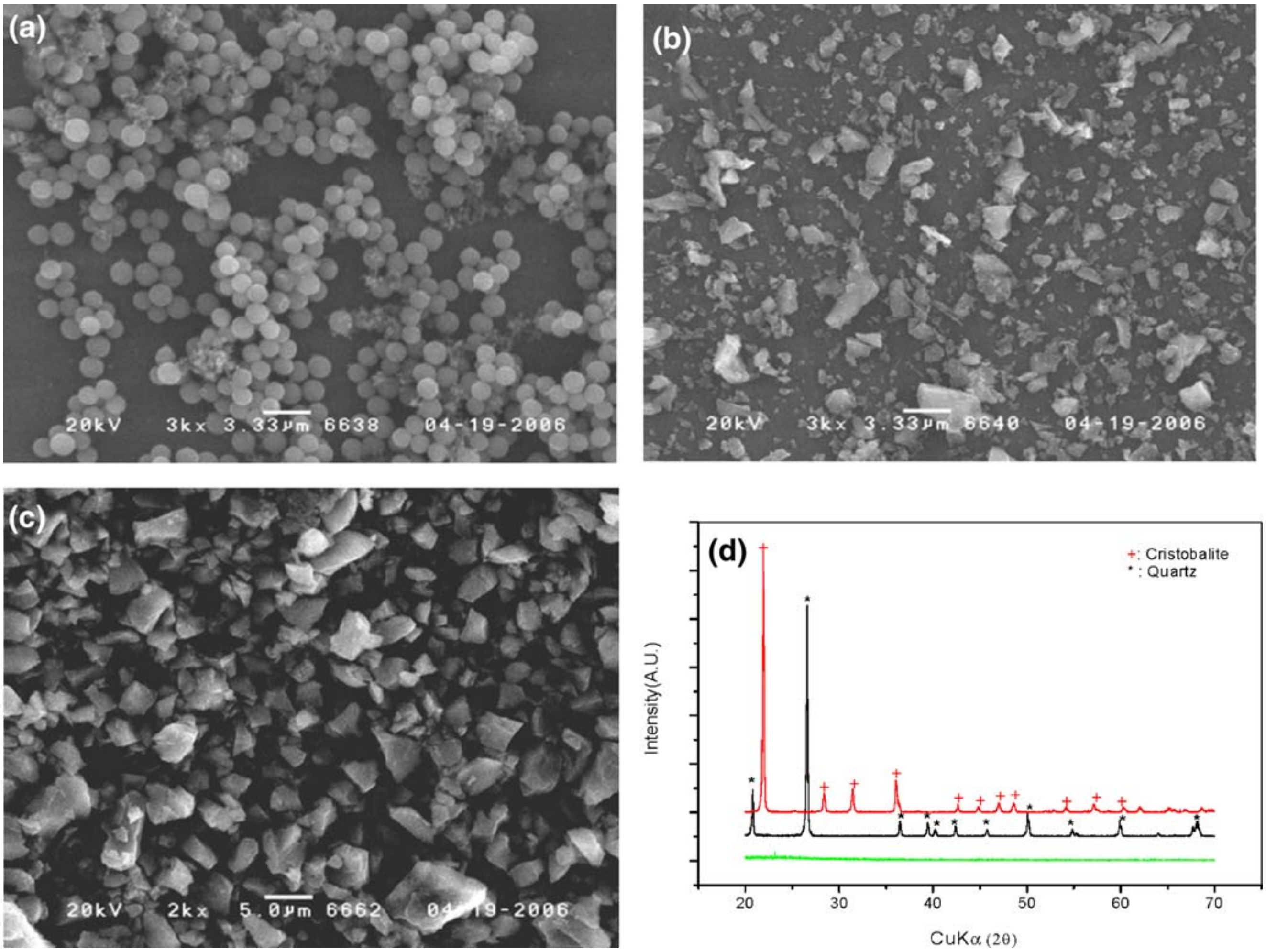

Fig. 1 Powder morphologies and XRD pattern. (**a**) amorphous, (**b**) quartz, (**c**) cristobalite, (**d**) XRD pattern

three silica powders are shown in Table 1 and powder morphologies and crystalline phases can be seen in Fig. 1. As shown in Fig. 1(a), amorphous silica was spherical but both (b) quartz (c) cristobalite were not. Figure 1(d) shows XRD patterns of three kinds of powder. Benzocyclobutene (BCB, Dow Chemical, Cyclotene 3022-46/23, U.S.A.) was used as resin for composite. Used Cu foil (Iljin Copper Foil, Korea) had thickness of 35μ.

Mixing ratio of filler powder was changed from 10 to 40 volume %, and filler and resin were mixed for 5 min in centrifugal polymer mixer at 1,000 rpm. Mixtures were casted on shining surface of copper foil. Casted thick films were dried for 30 min at 170°C. Dielectric properties were

Table 1 Basic properties of silica powder.

	Crystalline state	Density [g/cm^3]	D_{50} [μm]	BET [m^2/g]
SiO_2	Amorphous	2.20	1.2	5.8896
SiO_2	Quartz	2.65	0.8	4.2519
SiO_2	Cristobalite	2.38	3.1	4.9740

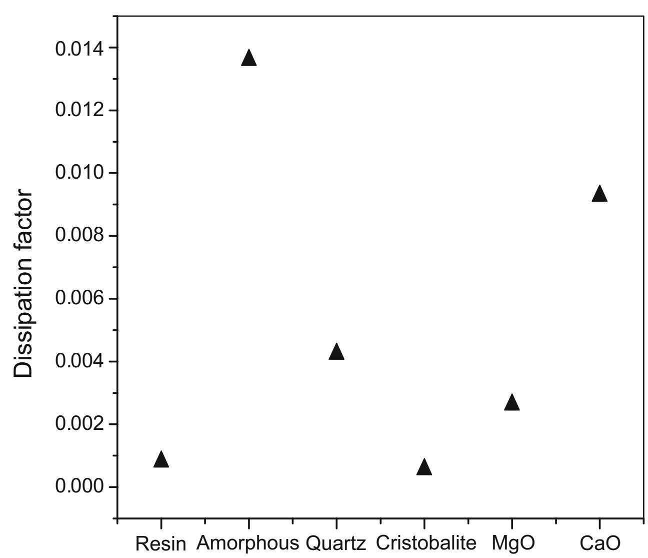

Fig. 2 Dissipation factors of various filler with BCB resin. (Mixing ratio of 20 volume %)

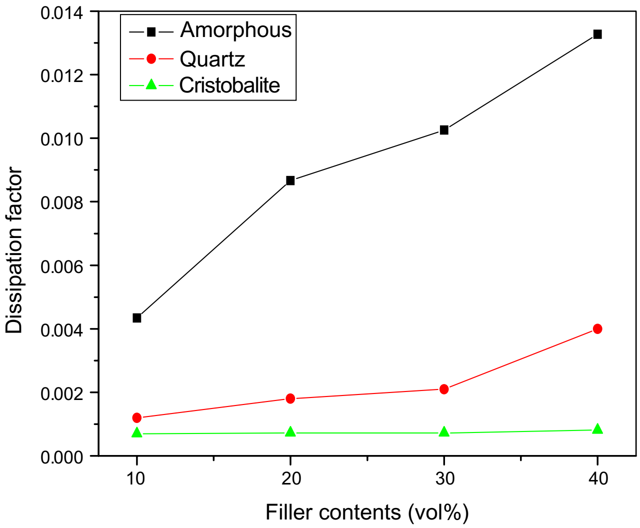

Fig. 3 Dissipation factors of three silica filler with variation of mixing ratio

evaluated with impedance analyzer (Agilent, 4294A/E4991A, U.S.A.) after printing circuit on fabricated film with Ag Paste (TED PELLA INC., No. 16034 Pelco colloidal silver liquid, U.S.A.) for room-temperature use.

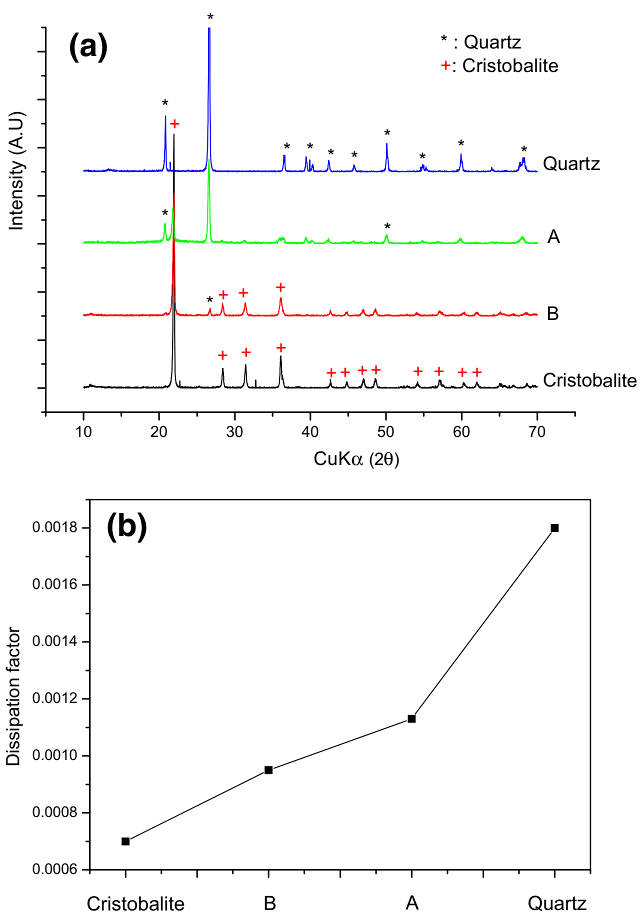

Fig. 4 (**a**) XRD patterns of filler materials, (**b**) dissipation factors of those fillers

3 Result and discussion

Figure 2 shows dissipation factors of casted films with various filler materials at mixing ratio of 20 volume %. BCB resin is known to have excellent electric property with dissipation factor of about 0.0008 [6] and measured value was almost same in this study. Crystalline cristobalite showed the lowest value, compared with those of other fillers. Dielectric constants could not be compared precisely due to deviations of film thickness.

Figure 3 shows dissipation factors of three crystalline phase of silica in casted films, with variation of mixing ratio from 10 to 40 volume %. Dissipation factors of amorphous and quartz silica filler increase as their quantities increase, while cristobalite silica shows almost unchanged values. From this, cristobalite is thought to have dissipation factor similar to that of BCB resin.

Dielectric constants of composite are, in general, expected to follow 'mixing rule,' while dielectric losses are reported little till now [7, 8] "Especially, when low-loss filler of amorphous silica was mixed, change of dielectric loss would have continuous value corresponding with volume." This result is thought to follow Lichtenecker's equation, which is taken as 'mixing rule' in 'dielectric constant' [7, 9]. Hence, loss property could be improved

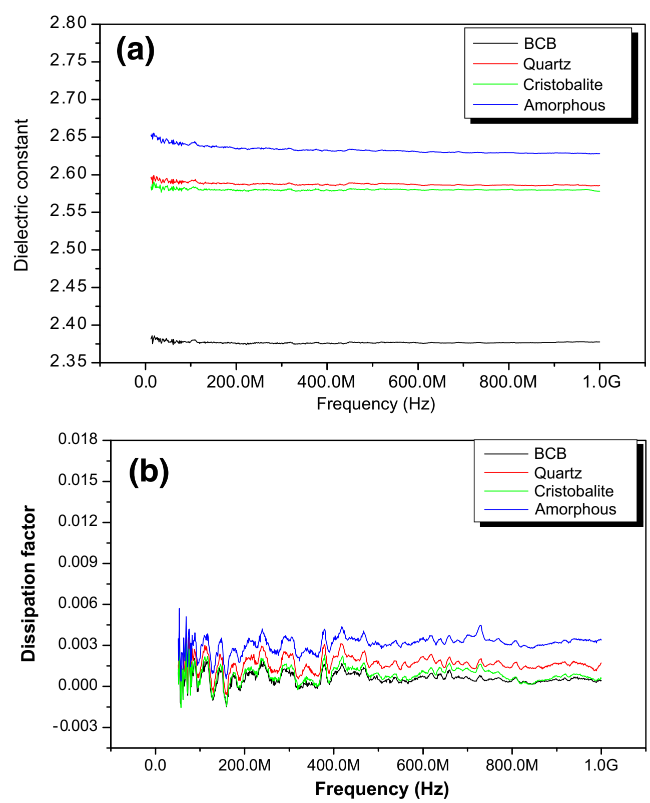

Fig. 5 Dielectric properties with frequency. (**a**) dielectric constant, (**b**) dissipation factor

with ceramic filler change though resin does not have low loss enough as can be known in this study.

In Fig. 4, changes of dissipation factors, with changes of crystalline phase of silica filler from cristobalite to quartz, are shown. In (a), 'A' and 'B' phases are intermediate phases between cristobalite and quartz though precise quantity of each phase could not be measured, and as quantity of quartz increases, dissipation factor increases as seen in (b).

Figure 5(a) and (b) shows dielectric constants and dissipation factors of several materials with variation of frequency from 1 MHz to 1 GHz for samples of 20 volume %. Dielectric constants and dissipation factors showed little changes with frequency and value order of each material did not change till 1 GHz, same as the result shown in Fig. 2. Dielectric constant of pure BCB measured 2.37 at 1 GHz, cristobalite 2.58, quartz 2.59 and amorphous 2.63.

The more the filler quantity, the more frequent the site where filler particles were torn apart, as shown in Fig. 6(a) and (b) were for amorphous and showed well-dispersed spherical powders in resin matrix. (c) and (d) for quartz, showed broken-shaped particles in resin matrix. As filler amount increased, voids among particles increased and this is thought to have made higher loss (e) and (f) for cristobalite, showed homogeneous composite without pore, even in 40% case.

4 Conclusion

Dielectric properties of low-loss dielectric materials are investigated with change of silica filler in PCB composite. It can be known that dielectric properties of filler materials are evaluated by casting method with use of polymer resin. Cristobalite has superior dissipation factor to other filler materials, as measured with BCB resin, and thought to reduce dielectric loss in PCB composite with resin. As crystalline quantity of cristobalite increases in cristobalite/quartz intermediates, dissipation factor decreases. Silica filler is thought to be with good accordance of mixing rule.

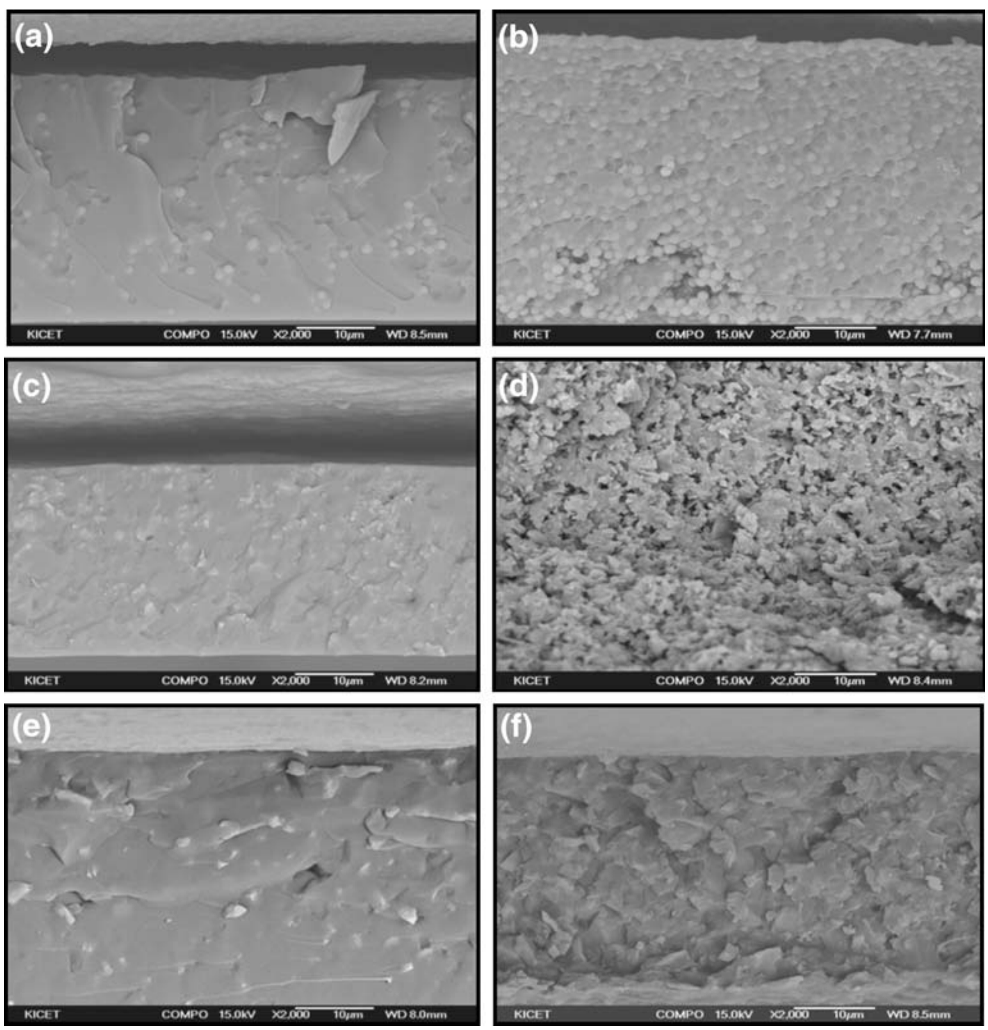

Fig. 6 SEM images of fracture profile with filler quantity. (**a**) amorphous 10 volume %, (**b**) amorphous 40 volume %, (**c**) quartz 10 volume %, (**d**) quartz 40 volume %, (**e**) cristobalite 10 volume %, (**f**) cristobalite 40 volume %

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