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Advancing 5G communications using LTCCs

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In 5G communication, millimeter wave (mmWave) radio frequencies are used to achieve ultra-high speed, large capacity, and ultra-low latency data transfers. However, mmWave transmissions can't penetrate buildings. To optimize 5G, more and smaller cell antennas are required. Use of low-temperature co-fired ceramic (LTCC) conductive pastes and tapes in radio frequency components (such as those used in band bass filters (BPF), substrates and antenna-in-package (AiP) for radio frequency front-end modules [RF FEM]) can help expand access to 5G mmWave bandwidth devices. Components made with LTCC materials have high reliability, excellent electrical performance, good thermal conductivity, and outstanding environmental resistance. In addition, the physical properties of LTCC materials enable a higher degree of design freedom compared to printed circuit boards because they allow for stacking up to 80 layers while still providing dielectric constant stability and low insertion loss. They have also been proven to enable smooth functioning across a wide frequency range – including high-frequency applications – in challenging environments.

LTCC uses and properties

LTCC material systems combine the benefits of multi-layer ceramic and thick-film technologies used in high-frequency, microwave, and mmWave electronic applications. Most often, these systems are used for high-reliability circuit boards. Recent developments have led to the use of LTCC materials in AiP for RF FEMs.

In the unfired green state, each layer of dielectric can be via punched, filled, and screen-printed with conductor and resistor traces (Figure 1). Up to 80 layers can be stacked together. Compared to traditional printed circuit boards that are limited to a few layers (usually 20 or fewer), LTCC materials allow for the design of more highly integrated circuitry. Plus, these materials are key to achieving high-performance efficiency at low levels of power consumption.

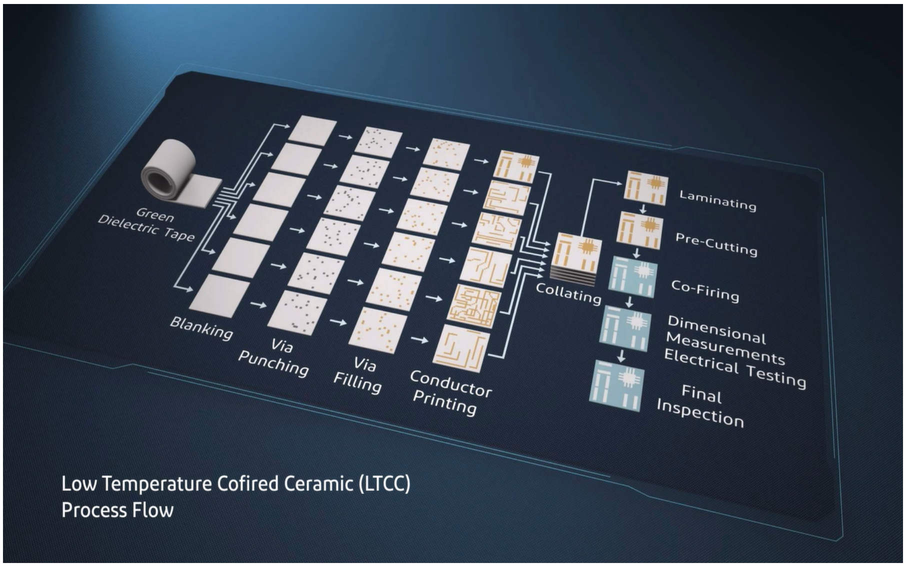

Figure 1: Low-temperature co-fired ceramic (LTCC) process flow.

After layers are stacked and laminated, they are co-fired at 850°C. This is much lower than the >1500°C used in conventional high-temperature co-fired ceramic (HTCC) processing. Circuits made with LTCC materials can also withstand post-firing of thick film, plating, soldering, or brazing to make a fully functional package (Figure 2).

LTCC materials combine the positive attributes of a thick film on a ceramic

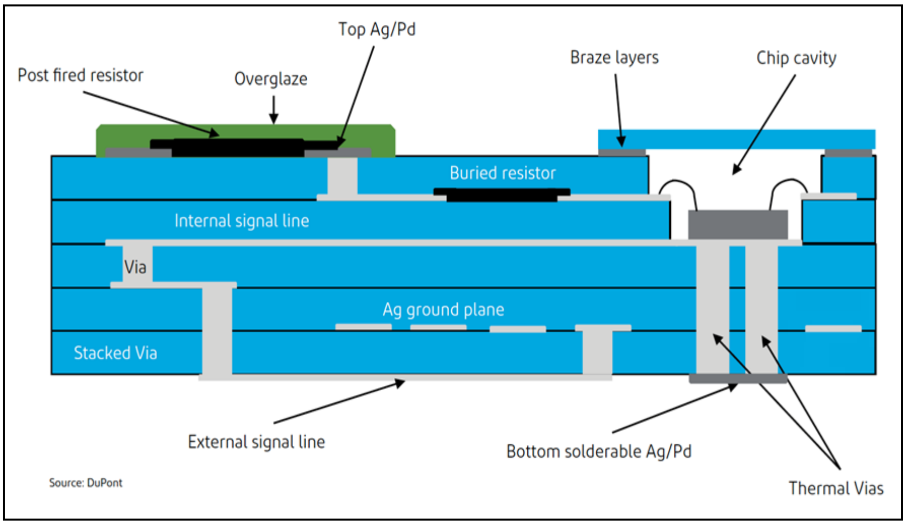

Figure 2: LTCC material systems allow package design flexibility with up to 80 layers for integrating passive components, e.g., capacitors and resistors, as well as the ability to create cavities, and physical properties that withstand post-firing.

Coefficient of Thermal Expansion Comparison			
	Printed Circuit Board	Semiconductor	LTCC materials
ppm/K	13-17	4-6.5	5.3

Table 1: CTE of LTCC materials is close to the CTE of a semiconductor material.

Thermal Conductivity Comparison of Various Substrate Materials							
	DuPont™ GreenTape™	General LTCC	LCP	PTFE + Ceramic	FR4	PTFE	PI
W/m-K	4.6	3.3	3	0.5	0.25	0.25	0.12

Table 2: Thermal conductivity comparison among different types of substrates.

substrate and HTCC. Like thick film, LTCC materials can be used with high-conductivity metals (e.g., Au and Ag), have a low dielectric constant (Dk), can be used to print resistors, and are processed at a relatively low temperature. Like HTCC technology, LTCC materials allow high resolution for printed conductors, use a single firing, provide good dielectric thickness control, and multiple layers.

LTCC is inherently hermetic and therefore immune to moisture absorption. The coefficient of thermal expansion (CTE) of certain LTCC materials are much lower than the CTE of printed circuit boards. This allows for a close match to integrated circuit (IC) chips (Table 1). Compared to general LTCC materials and other circuit board materials, DuPont™ MCM GreenTape™ offers better thermal conductivity (Table 2).

With induced low-dissipation factor (Df) degradation, DuPont™ GreenTape™ dielectric properties are very stable with respect to temperature (Figure 3) because of a low CTE, and polarization modes that are not strongly influenced

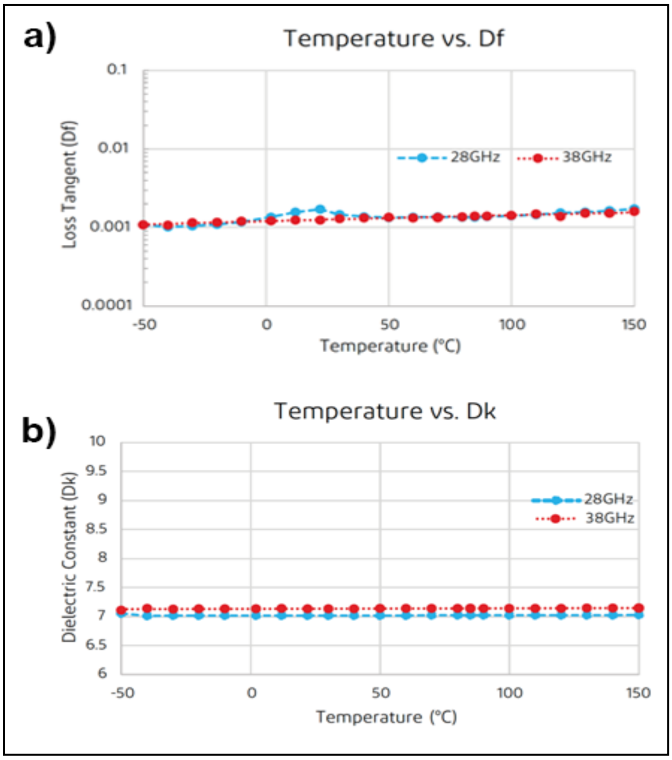

Figure 3: DuPont™ GreenTape™ maintains: a) a low dissipation factor (Df), and b) a low dielectric constant (Dk) in extreme cold and extreme heat.

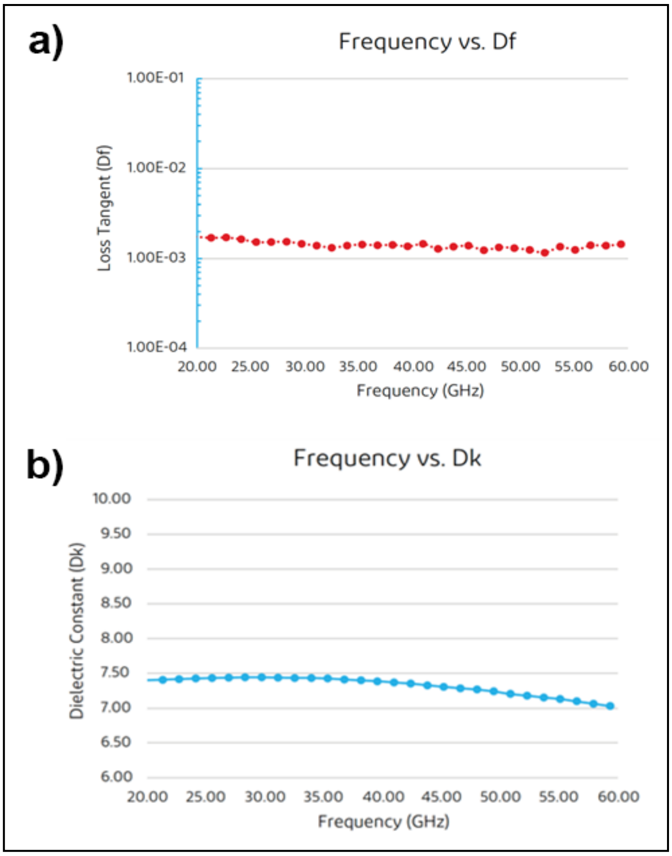

Figure 4: DuPont™ GreenTape™ provides: a) a low loss tangent (Df), and b) a stable dielectric constant (Dk) over a range of mmWave frequencies.

by ambient temperatures. At the same time, the tape has a very low loss tangent of transmissions over mmWave frequencies (Figure 4). For the reasons outlined above, we chose this tape as a test material for AiP applications.

AiP prototyping, testing, and validation

Our Microcircuit and Component Materials team collaborated with the Industrial Technology Research Institute (ITRI) of Taiwan to design and test mmWave AiP prototypes made with DuPont™ GreenTape™. After firing, test results indicate that the electric properties of LTCC substrates perfectly match the design, with an attainable bandwidth of 2GHz and higher as shown in Figure 5. After chips and passive components were packaged onto the substrates (Figure 6), further testing in an anechoic room was used to validate beam-forming properties.

Once installed in the system (Figure 7), the antenna module underwent mmWave signal transmission field testing. Because of its low-loss features, we could validate the quality of signal transmission by using error vector magnitude (EVM) testing (Figure 8). We observed the clean image and audio at the receiving end when a high-resolution video file is transmitted from one device to another (Figure 9). This fully demonstrates the feasibility of using our tape system in AiPs for mmWave applications.

Future development

Using highly-integrated circuitry and exceptionally stable and reliable low-loss LTCC materials in the antennae arrays (or multiple antennae in one or more arrays) and RF

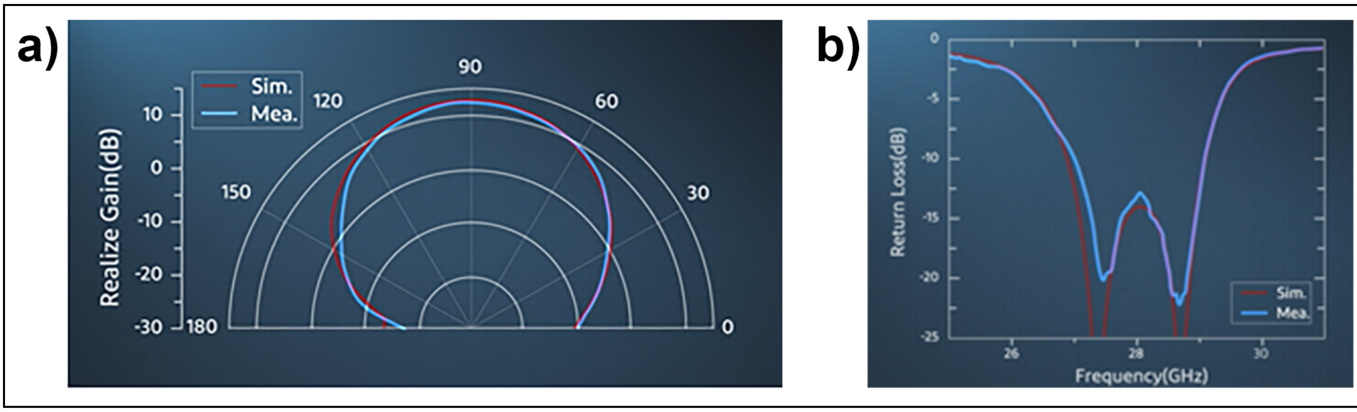

Figure 5: Measurement results a) realized gain, and b) return loss, match simulation results after the LTCC substrate was fired.

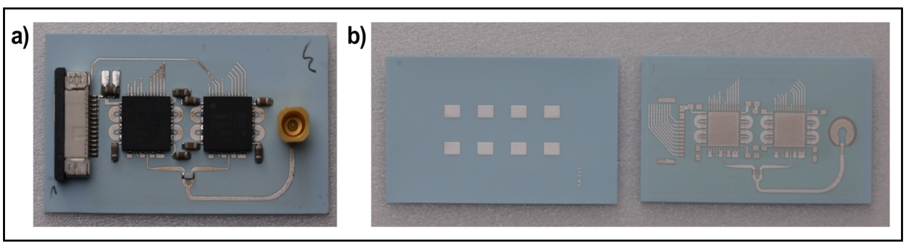

Figure 6: a) (left) Surface-mounted IC chips, and b) fired LTCC substrate.

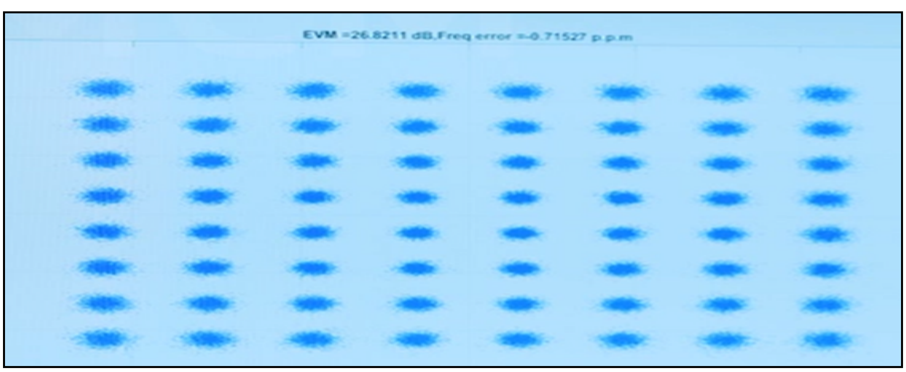

Figure 8: EVM testing result.

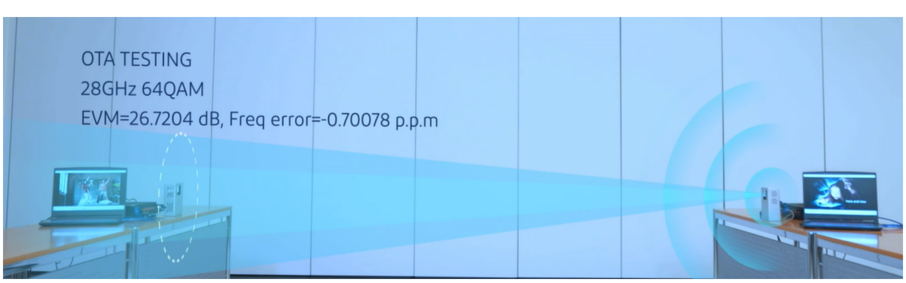

Figure 9: Signal testing showed that antenna prototypes made with DuPont™ GreenTape™ have low loss and provide clean image and audio transmission of high-resolution video files.

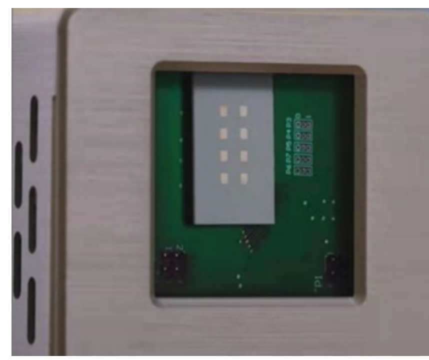

Figure 7: A LTCC AiP module installed into a device.

FEM are key to achieving high 5G performance efficiency at low levels of power consumption. The outcome of our LTCC testing—showing its ability to maintain good thermal stability and heat performance while significantly reducing insertion loss—opens the door to developing new AiP substrates in which their size is reduced along with signal loss.

Summary

LTCC materials deliver both superior environmental tolerance and a high level of design freedom in high-frequency applications. These materials could play an important role in advancing instant communication for autonomous vehicles that talk to each other, as well as for applications for 5G mmWave band communications, military operations, remote surgery, robotics, and more.

Biography

Andy Kao is a Global Telecom Segment Leader at DuPont Microcircuit and Component Materials in Taiwan where he develops new solutions for 5G and high-frequency applications. He received a Master's degree in Material Science from National Taiwan U. Email: Andy.Kao@dupont.com