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Preparation of Alumina Thick Films by Aerosol Deposition Method for Integrated RF Modules

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The aerosol deposition (AD) process will be proposed as a new fabrication technology for the integrated RF modules. α-Al_2O_3 thick films were successfully grown on glass and Al substrates at room temperature by the AD process. Relative dielectric permittivity and loss tangent of the Al_2O_3 thick films on Al showed 9.5 and 0.005, respectively. To form microstrip lines on aerosol-deposited Al_2O_3 thick films, copper electroplating and lithography processes were employed, and the square-type cross section with sharp edges could be obtained. Low-pass LC filters with 10 GHz cutoff frequency were simulated by an electromagnetic analysis, exhibiting the validity of the AD process as a fabrication technology for integrated RF modules.

Key words: aerosol deposition, integrated RF module, Al_2O_3 thick films, integral substrate

1. INTRODUCTION

Today's electronic devices, such as cellular phones, personal digital assistants (PDAs) and personal computers, continue to be subjected to the trend of added functionality with wireless interfaces and high operating speeds and of the miniaturization by high integration of electronic components. However, the number of active and passive components considerably increases as functionality of electronic devices increases. Especially, passives account for 80 to 95 % of the total number of components and consume up to 40 % of the surface area on printed wiring boards (PWBs). Therefore, the surface mounting technology (SMT) of passive components, such as discrete parts, arrays, networks and integrated passive devices, will be greatly required to be embedded into the PWBs using embedded passive technology (EPT).[1,2] The advantages of EPT can be enumerated as follows. By deceraseing the number of SMT discrete passives on PWBs and assembling circuitary layers into 3-dimensional multilayers, higher packaging densities are allowed to be achieved. In addition, EPT possesses the potential for lower costs by reducing the number of surface mounting devices, flux, and solder pastes used. EPT are also expected to simplify the assembly process reducing assembly costs especially when 0201 components have to be used. Moreover, capacitors could be placed directly underneath the active components shortening distance between the passives and active components so that the parasitics associated with SMT passives can be reduced to result in better signal transmission and less cross talk. Additional advantage gained would include a large reduction in the number of solder joints leading to improved reliability. Candidates of the present fabrication technologies for embedded passives (or integral substrates) are Low Temperature Co-firing Ceramics (LTCCs)[3,4] and polymer-ceramic composites[5,6]. LTCCs need still high temperature process at around 850 °C leading to low size accuracy due to shrinkage during firing, limitations on the use of materials caused by inter-diffusion and reactions, difficulty in embedding of active devices and chip components. And polymer-ceramic composites show degraded electric properties, low permittivity and low heat extraction compared with ceramics in spite of being able to fabricate lower than 200 °C and to embed active devices in the multilayer structure circuitry.

If ceramic thick films can be grown at room temperature, all of the problems mentioned above are expected to be overcome. In this article, we propose a new novel technology to fabricate integrated RF modules by employing the AD process proposed by Akedo[7-9].

2. EXPERIMENTAL

The AD process is based on shock loading solidification due to the impact of ultrafine ceramic particles accelerated by means of carrier gases and a nozzle. Figure 1 illustrates the AD apparatus. Al_2O_3 thick films were fabricated on glass or Al substrates by the AD process. Fine α-Al_2O_3 particles (Showa Denko K. K.) with 0.4 µm in average diameter and purity of 99.8 % were used as starting materials. Al_2O_3 particles become a state of aerosol in the aerosol chamber by means of the vibration and mixing system. The particles are transported by He gases and accelerated through a nozzle. Films are grown at room

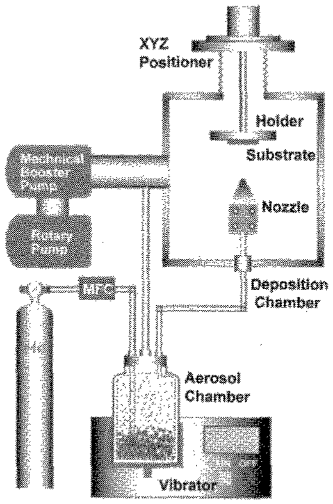

Fig. 1. Schematics of the aerosol deposition apparatus.

temperature by the impact of the particles on substrates. The deposition conditions for Al_2O_3 thick films by the AD process were summarized in Table 1. The microstructure and crystallinity of the Al_2O_3 thick films were examined by a scanning electron microscope (SEM) and X-ray diffractometer (XRD), respectively. Their dielectric properties were measured from 1 kHz to 10 MHz by an impedance analyzer (HP4194A). Copper electroplating and electro-beam lithography were employed to form fine microstrip lines and the dimensions of copper transmission lines for characteristic impedance of 50 Ω were determined by an electromagnetic (EM) analysis. To demonstrate the validity of the AD process as a new novel process for integral substrates of microwave devices, low pass filters with the cutoff frequency of 10 GHz were simulated using an EM analysis by taking into account of electrical properties of Al_2O_3 thick films obtained by the AD process.

Table I. Experimental conditions of Al_2O_3 thick films by the aerosol deposition process.

Powder	α-Al_2O_3(SG160A,SG160B)
Substrate	Glass and Al
Carrier Gas	He
Size of Nozzle Orifice	5×0.3 mm^2, 10×0.4 mm^2
Scanning Rate	1.2 mm/sec
Working Pressure	300~800Pa
Consumption of Carrier Ga	4.5~9 L/min
Distance between Substrate and Nozzle	10~35 mm
Deposition Temperature	room temperature
Deposition Time	10~60 min
Deposition Area	5×20 mm^2
Vibration Speed	150~350 rpm

3. RESULTS AND DISCUSSION

3.1 Al_2O_3 thick films fabrication by AD process

Al_2O_3 thick films were deposited on glass substrates by the AD process for the optimization of experimental parameters. When using SG160A powders, only Al_2O_3 compacts were formed regardless of wide changes in deposition conditions. On the contrary, dense Al_2O_3 thick films could be deposited on glass substrates at room temperature by the use of SG160B powders under the some conditions. Through the observation of a SEM, it was revealed that SG160A powders were severely aggregated with a diameter of 50~200 μm, but SG160B powders were dispersed. It is thought that severally aggregated Al_2O_3 particles play a role of a cushion to absorb kinetic energy, resulting in formation of a compact. Therefore, SG160B powders were chosen to grow Al_2O_3 thick films on Al substrates. Figure 2 shows the plane-view and cross-sectional SEM micrographs of Al_2O_3 thick films deposited on Al substrates at room temperature. The thickness is about 15 μm. The surface of as-deposited

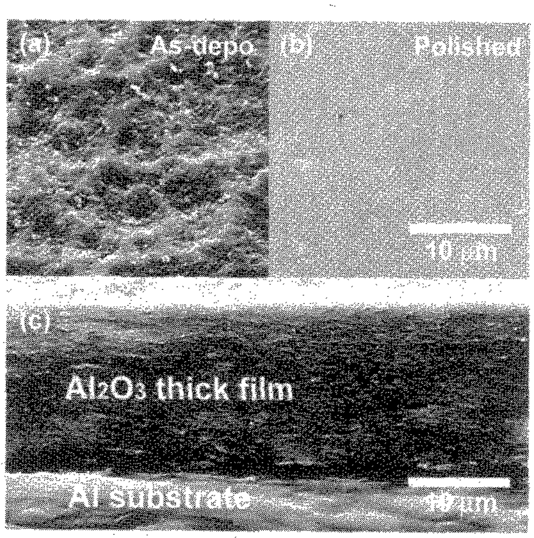

Fig. 2. Plane-view SEM micrographs of (a) as-deposited, (b) polished, and (c) a cross-sectional SEM micrograph of Al_2O_3 thick films on Al substrates at room temperature.

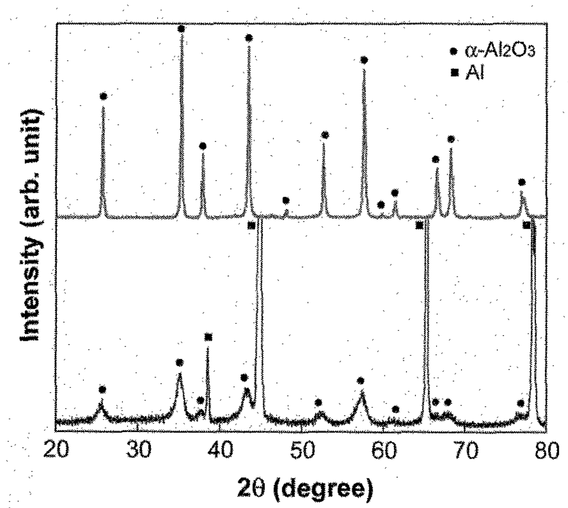

Fig. 3. X-ray diffraction patterns of (a) Al_2O_3 powders (SG160B) and (b) aerosol-deposited Al_2O_3 thick films on Al substrates at room temperature using SG160B powders.

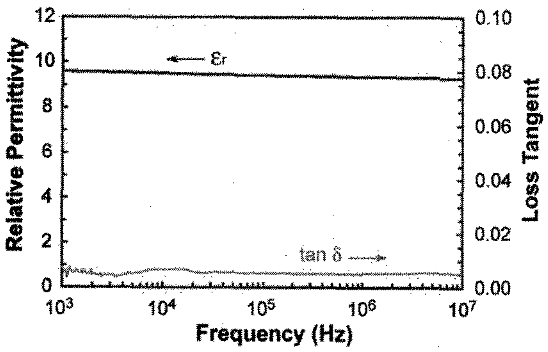

Fig. 4. Frequency dependence of the relative permittivity and loss tangent of aerosol-deposited Al_2O_3 thick films.

films had a kind of craters formed by the impact of particles, but smooth and flat surface could be obtained by polishing them. And it was confirmed that the thick films are very dense. From the XRD patterns of the thick films grown on Al substrates as shown in Fig. 3, it was revealed that a single α-Al_2O_3 phase exists without any second phases despite being deposited at room temperature.

After polishing the surface of the Al_2O_3 thick films, gold upper electrodes were formed by sputtering using a metal mask and dielectric properties were measured by an impedance analyzer. As shown in Fig. 4, relative permittivity and loss tangent of the Al_2O_3 thick films were 9.5 and 0.005 at 1 MHz indicating that their dielectric properties are as good as those of Al_2O_3 ceramics. These aerosol-deposited Al_2O_3 thick films give better dielectic properties than the polymer-ceramic composites and are sufficient to be utilized as integral substrates in microwave range.

3.2 Copper electroplating for microstrip lines

Copper electroplating was performed and mirror-like copper films on sputter-deposited Pt/Al_2O_3 substrates could be obtained by optimizing current density. The optimum current density was determined to be 3.6 mA/cm^2 by taking into account of the controllability of

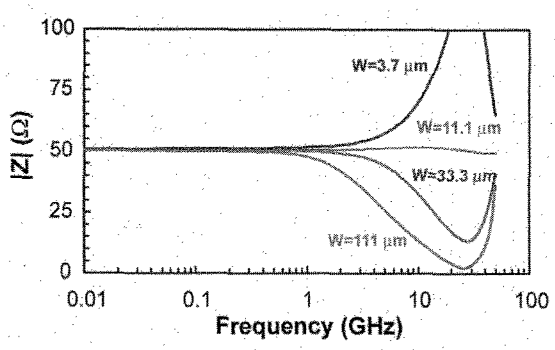

Fig. 5. Dependence of the characteristic impedance with the variation of the width of copper lines on aerosol-deposited Al_2O_3 thick films.

thickness of copper films. Under this condition, fine-patterned Cu trnsmission lines were formed on aerosol-deposited Al_2O_3 thick films on Al substrates by introducing fine-patterned Pt films using a conventional lift-off process.

An electromagnetic (EM) anaysis was carried out to determin the dimensions of copper transmission lines with the characteristic impedance of 50 Ω. Figure 5 shows the dependence of the characteristic impedance with the variation of the width of copper lines in which the thickness of copper (ρ=1.72×10^{-8} Ωm) is 5 μm and the thickness of Al_2O_3 (ε_r=9.5, tan δ=0.005) is 10 μm. It was known that the characteristic impedance maintains 50 Ω over 10 GHz range when the width of a copper line is 11.1 μm. Based on the results, the copper transmission lines were formed on 10 μm-thick Al_2O_3 thick films. Figure 6 shows the laser microscope micrographs of a fine copper-electroplated transmission line. We could obtain the designed dimensions of copper electroplated lines. Moreover, the shape of the copper transmission line was square with sharp edges which exhibit good transmission characteristics. As a result, it is shown that the circuitry can be miniaturized for integral substrates for microwave devices through establishing the aerosol deposition process of Al_2O_3 thick films and the fine patterned copper electroplating.

3.3 Simulation of LC filters

To demonstrate the validity of the aerosol deposition process as a new fabrication technology for RF module, the 2-order Butterworth low pass LC filter with the cutoff frequency of 10 GHz and the impedance of 50 Ω were simulated using the electrical and dimension parameters obtained. By the theoritical calculation for the LC filter, it was obtained that the values of inductance and

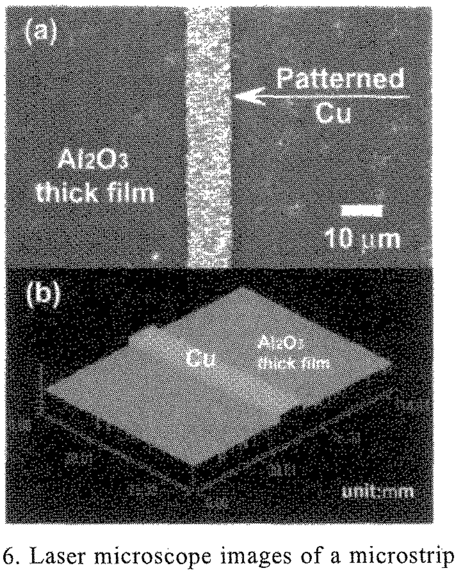

Fig. 6. Laser microscope images of a microstrip line formed on aerosol-deposited Al_2O_3 thick films by copper electroplating.

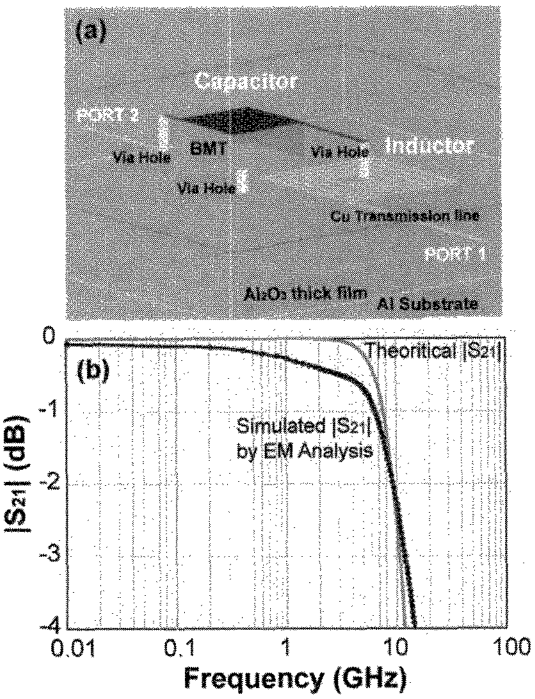

Fig. 7. (a) 3-dimensional structure of the second order Butterworth low pass filter consisted of a spiral-type inductor and a $Ba(Mg_{1/3}Ta_{2/3})O_3$ (BMT) microwave capacitor and (b) theoretical and simulated transmission characteristics.

conductance were 1.13 nH and 0.45 pF, respectively. First, the dimensions of inductors and capacitors were independently determined using the EM analysis in which the spiral-type inductor with 4 turns was used, and the dielectric properties of microwave dielectric ceramics $Ba(Mg_{1/3}Ta_{2/3})O_3$ was used. And then, by the combination of the inductor and capacitor, the filter characteristics was simulated. Figure 7 shows the transmission characteristics $|S_{21}|$ calculated by a circuit simulator and the EM analysis by taking into account of the parameters of materials and dimensions. It was confirmed by this simulation that LC filers with small size (0.2×0.4 mm^2) can be fabricated on Al_2O_3 films deposited by the AD process.

3.4 Proposal of new integrated RF modules

Though this study, we propose a new RF module as shown in Fig. 8. First, substrates are prepared by machining Al metal plates to make through-holes and so on, and then Al_2O_3 thick films and dielectric thick films for decoupling capacitors are deposited by the AD process. After fabricating 2-dimensional circuitry independently, 3-dimensional circuitry is assembled by stacking the 2-dimensional circuitry. Advantages of this fabrication technology are thought of as follows; 1) high density integration (fine microstrip lines at 50 Ω and multilayer structures), 2) high heat extraction, 3) embedding of active components, 4) suppression of noise problem (shielding effects of metal plates), 5) high dimension accuracy (no sintering shrinkage), 6) low cost and 7) recycling.

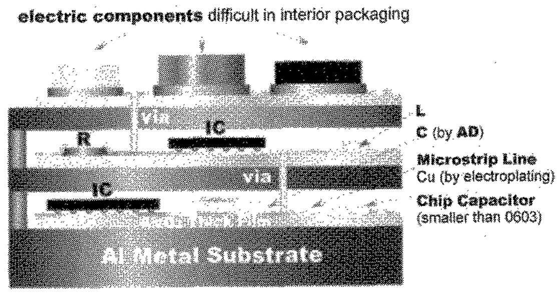

Fig. 8. Proposal of new RF modules by embedding both active and passive components using AD process.

4. CONCLUSIONS

The aerosol deposition (AD) process was proposed as a new fabrication technology for the integrated RF modules. Dense α-Al_2O_3 thick films were successfully grown on glass and Al substrates at room temperature by empolying the AD process. Relative dielectric permittivity and loss tangent of the Al_2O_3 thick films on Al were 9.5 and 0.005, respectively. The optimum current density for the copper electroplating was 3.6 mA/cm^2 by taking into account of the controllability of thickness of copper films and smooth and flat surface. Fine microstrip lines with the square-type cross section and sharp edges could be obtained on the aerosol-deposited Al_2O_3 thick films by means of copper electroplating and lithography processes. Through the simulation of low-pass LC filters with 10 GHz cutoff frequency, the validity of the AD process as a fabrication technology for integrated RF modules could be confirmed.

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