Preparation and Characteristics of Integrated Capacitor for RF devices

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Abstract
The technology of the IPD's(integration passive devices) includes material design and micro-fabrication, which are core technologies in the present work, integration circuit design and fabrication process. In this work, the preparations and characteristics of for RF integrated capacitor with Ta_2O_5 (tantalum pentoxide) as a dielectric material are investigated. These kinds of capacitors can be applicable to the passive components utilized in voltage controlled oscillator(VCO), low noise amplifier(LAN), mixer and synthesizer for mobile telecommunication of radio frequency band 900 MHz to 2.2 GHz, and in a library of passive devices for RF integration circuit.

The present study presents the fabrication, oxidation and annealing of Ta_2O_5 capacitor for RF integrated capacitor in frequency range of 900 MHz to 2.2 GHz which is the main frequency band used in today's commercial wireless communication. The results show that work paper Ta_2O_5 capacitor for RF integrated capacitor may be applicable to the RF integrated capacitor passive components for mobile telecommunication. Also, Inductor and resistor are integrated as a one module under the library or RF passive devices.

Key word : Passive devices, capacitor array, RF IC, tantalum pentoxide, library, inductor,

Introduction

Recently, multi-component module, SMD, MLCC chip, etc., have been widely used as a passive component with resistor, inductor and capacitor. The dielectric material of the capacitor element should have the requirements including high dielectric constant, low temperature coefficient, stable frequency properties and high Q-factor. In order to realize miniaturization and integration of passive capacitor or DRAM, thinner dielectrics, high density integration, high dielectric constant, low leakage current and high Q-factor should be needed. Although conventional dielectric materials such as silicon oxide (SiO_2), silicon nitride(Si_3N_4), SiO_2/Si_3N_4 and tantalum nitride(TaN) have been improved in dielectric properties, the attempts to improve their properties have limitations to decreasing cell size, dielectrics thickness and leakage current, and increasing of dielectric constant and complex introducing process [1, 2]. Since the early 1980's, Silicon Valley scientists have given an attention to tantalum pentoxide (Ta_2O_5) as next generation dielectrics for memory capacitor. The Ta_2O_5 film draws much interest as a memory and integrated circuit capacitor material in providing high rating capacitance, low leakage current, high breakdown voltage, low error and temperature-dependent properties leading to low failure [3]. The general Ta_2O_5 thin films can be obtained from the thermal evaporation, sputtering, thermal oxidation, LPCVD, etc. The physical properties of Ta_2O_5 is known as different by the fabrication process. Nowadays, for the Ta_2O_5 thin films, the optimization of fabrication method, process improvement and annealing conditions have been extensively investigated. However, there are few reports on the adaptation of Ta_2O_5 thin films to high frequency IC capacitor and inductor [4-6].

In this work, the preparations and characteristics of capacitors for RF IC with Ta_2O_5 (tantalum pentoxide) as a dielectric material are investigated. These kinds of capacitors can be applicable to the passive components utilized in voltage controlled oscillator(VCO), low noise amplifier(LAN), mixer and synthesizer for mobile tele communication of radio frequency band(900 MHz to 2.2GHz), and in a library of monolithic microwave integrated circuit(MMIC). The present study presents the fabrication, oxidation and annealing of Ta_2O_5 dielectrics, in order to develop Ta_2O_5 capacitor for RF IC in frequency range of 900 MHz to 2.2 GHz which is the main frequency band used in today's commercial wireless communication. The results show that these Ta_2O_5 integrated capacitor array for RF IC may be applicable to the RF passive components for mobile telecommunication.

Experimental

Tantalum pentoxide(Ta_2O_5) thin film for metal- insulator-metal(MIM) capacitor is deposited by RF magnetron O_2 reaction sputtering. The discharge power for all procedures was fixed at 250 W and the ratio of oxygen reactive gas was 80:20(Ar : Oxgen) to fabricate oxide film. The substrate, Si p-100 wafer and alumina was cut by 21×21 mm and then contaminant is removed by rinsing in acetone and methanol, followed by cleaning with ultrasonic vibrator. Native oxide layer was removed with hydrofluoric acid(HF) solvent of 10 %. The cleaned substrate is oxidized in diffusion furnace at 950 □, for 30 min, and then SiO_2 layer was formed with 1000 □ on the substrate as a barrier of RF loss diffusion between thin film and substrate. As an adhesion layer to improve adhesion between substrate and thin film, titanium of 350□ was deposited for buffer layer.

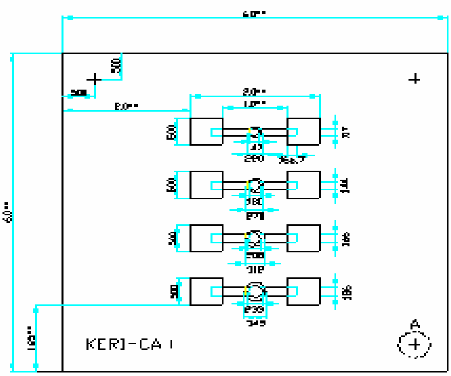


Fig. 1 Capacitor array of type "I" for design

After parameters were set up according to the properties of unit capacitor, interference of electro wave for array "I" was checked with Ansy's(Version 6.0) the analysis program of electro-magnetic. In network formation, array No. I is C_1, C_2, C_3 and C_4 is shown in figure 1. Ta_2O_5 capacitor array was measured on dielectric characteristics of unit capacitor and thin films with RF impedance analyzer(Agilent E 4991A) ranging from 1 MHz ~3 GHz. Array "I", "II" were interpreted with S-parameter and equivalent circuit by network analyzer

(Agilent E 8752 ES). Electrode tip for RF band was measured by Probe station(M & M summit 4900) and GGB pico-probe(figure 2).

Results and Discussion Experimental

In the present study, conditions of dielectric material with good properties are chosen among the films deposited by sputtering previously stated, followed by the oxidation and annealing. RF IC capacitor array is fabricated through lift off integration process. Finally capacitor capacitance has the range of 0.04 pF~0.4 pF for application to VCO, and the array is fabricated by dividing into two arrays (I, II). The fabricated capacitor array (I) is shown in figure 3. Figure 3-(a), (b) shows the cross section of capacitor and array fabricated by lift-off. Step coverage about 0.8 is relatively good.

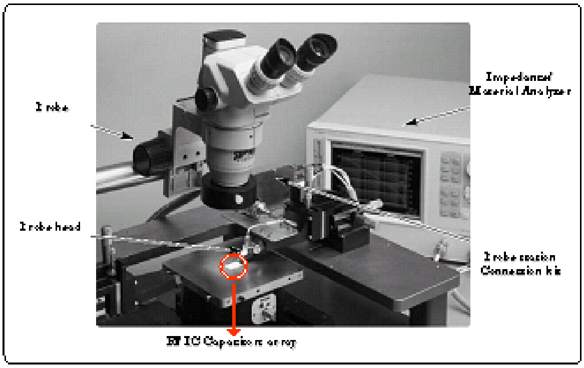


Fig. 2 Porbe station and RF impedance analyzer

RF integrated capacitor was fabricated by lift off process, and the results of impedance measurement are shown in figure 4. In the figure 4, (a) denotes Ta_2O_5 capacitor for IC, (b) chip capacitor impedance used in mobile phone of 900 MHz band at present. The measurement frequency □1 and □2 were placed 1.8 GHz and 2.2 GHz repectively. The figure (a) shows 2.5 ~ 3.0 pF maintained at the band of 1.8 GHz and Q-factor around 2.6. However, resonance occurs more or less after 1.8 GHz and Q-factor becomes lower as frequency increaseds.

(a) (b)

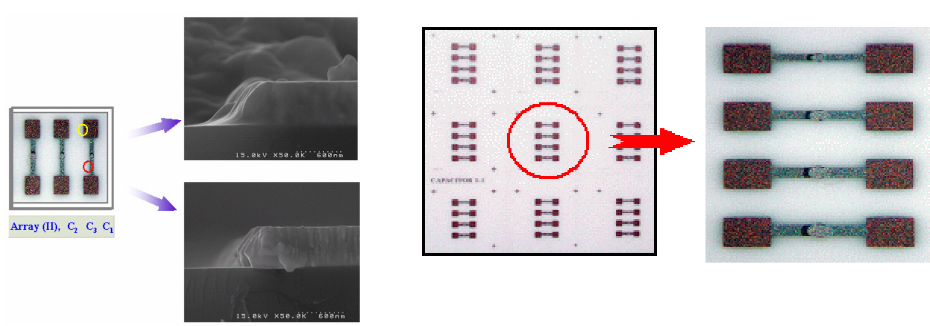
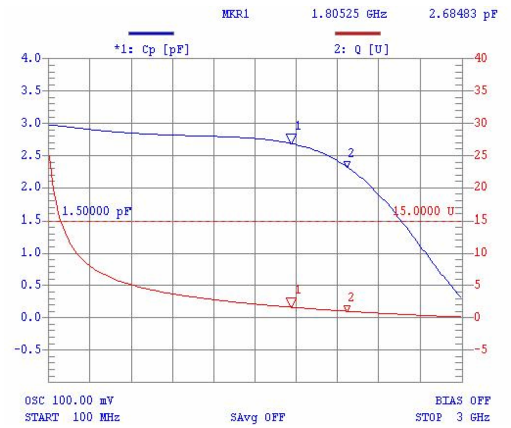


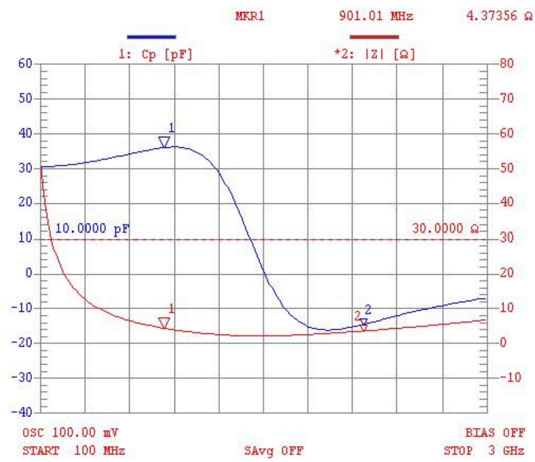
Fig. 3 Fabricated capacitors array and cross section

Frequency property and Q-factor are improved more or less, nevertheless, expansion of resonance frequency is necessary in order to apply to VCO, as a final target in present study or frequency band of general mobile telecommunication. For increment of Q-factor and expansion of resonance frequency, it is necessary to make size or thickness of capacitor smaller or thinner and to reduce resistance factor of electrode or leakage current of dielectrics.

In this study, the increment of loss is considered to be caused by mostly micro defects. Figure 4-(b) shows the characteristics of RF impedance of chip capacitor in frequency range of 900 MHz. The chip capacitor is utilized in matching circuit in the fore part of antenna in mobile phone. Resonance is known to occur after 900 MHz and Q-factor to exist in the range of 4~5.



(a)



(b)

Fig. 4 The characteristics of RF impedance
(a) RF IC capacitor, (b) chip capacitor.

Figure 5 is the results of measurement of S-parameter from 10 MHz to 3 GHz of fabricated RF IC Ta_2O_5 capacitor array (□ and C3). In the figure, □1 is 1.8 GHz around, then capacitance is 385 fF, impedance is 11 Ω and S-parameter property is relatively good. Increment of impedance slightly by heightening frequency is considered to be due to the increment of series resistance shown around solder of SMD component of 3.5 mm. Comparison of component S-parameter and equivalence model S-parameter in the rage from 900 MHz to 1.8 GHz shows that the equivalence model value coincides with the experimental value.

Lumped Element ESC used RF IC capacitor fabricated as a electric modeling is shown in figure 6. This model is designed to apply to 6 GHz frequency, but Q-factor or resonance frequency property are insufficient. C_p denotes capacitance value with modeling component, and L_{m1} and C_{m1} denote parastic factors of substrate and bottom electrode. L_{ma} and C_{ma} are parastic factors related to top electrode.

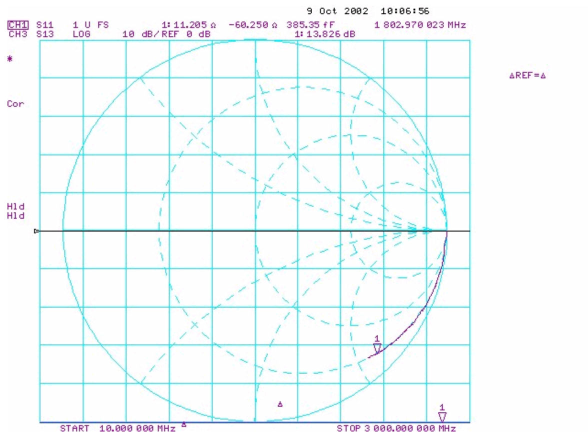


Fig. 5 S-parameter characteristics of RF IC Capacitor (C-II, C_3).

Res is a term that presents resistive loss and dielectric loss between both electrodes of integrated capacitor, where depends on Ta_2O_5 dielectric loss much. There are two characteristics for existing capacitor ESC with Ta_2O_5 as a dielectric material [7, 8]

□ Because bottom electrode and top electrode have mutual symmetric RF characteristics, capacitive parastic factor is come under the existence of both sides ($L_{m1} = L_{ma}$, $C_{m1} = C_{ma}$).

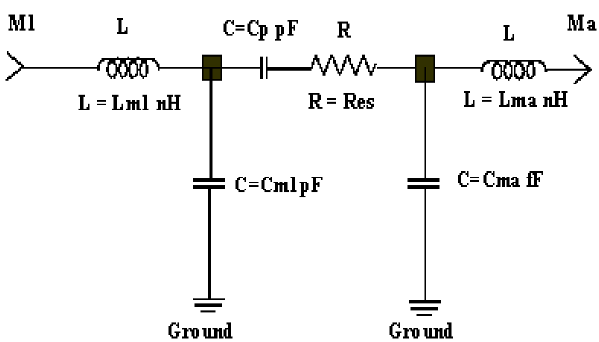


Fig. 6 ESC of capacitor for RF IC

 It is assumed that dielectric material of Ta_2O_5 thin film has low loss and resistance Rs existing in interface with electrode is close to "0"

Conclusion

In this work, the process and characteristics of Ta_2O_5 capacitor for RF IC element are investigated. The results may be summerized as follows.

Preparation of RF IC capacitor with Ta_2O_5 dielectrics should be possible by lift-off process. This capacitor shows that dielectric dispersion do not occur until 1.8 GHz, and a new RF IC capacitor array with high Q-factor over 2.6 is obtained. The measured capacitance of the RF IC capacitor array fabricated on a substrate is well coincided with the designed value of 0.04 pF~0.4 pF, and it shows better impedance characteristic. This capacitor array can be applicable to VCO, MMIC and band-pass filter.

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