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High-Q Embedded Spiral Inductor on Anodized Aluminum Substrate

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1. Introduction

Performance of an inductor, that is essential element of RF circuits, is estimated by a quality (Q) factor defined as a ratio of net energy stored by magnetic field and the average power dissipation in one cycle. Therefore, high Q factor can be achieved by reducing the power dissipation of an inductor. There have been various approaches to reduce power dissipation - reduction of substrate loss by using an advanced substrate or structure such as high resistivity material, substrate etching, and suspending structures [1-3]. Although these major approaches succeeded in increasing Q factor due to low loss and low dielectric constant of substrates, they required high cost and high process complexity and revealed many packaging problems due to their structural instability and weakness. To overcome these practical obstacles, the anodized aluminum substrate technology has been extensively studied as a promising candidate for a new packaging platform of RF system due to its inherent low substrate loss, good heat dissipation, and especially low cost. [4-6].

In this work, we propose a noble structure and the fabrication process for high-Q spiral inductor embedded in the anodized aluminum substrate. To improve Q-factor, a 50 μm-thick signal line of spiral inductor was fabricated using micromachining process. The fabricated spiral inductor showed a high Q-factor of 82 at 4 GHz with inductance of 2.6 nH at 2 GHz and self-resonant frequency of around 10 GHz.

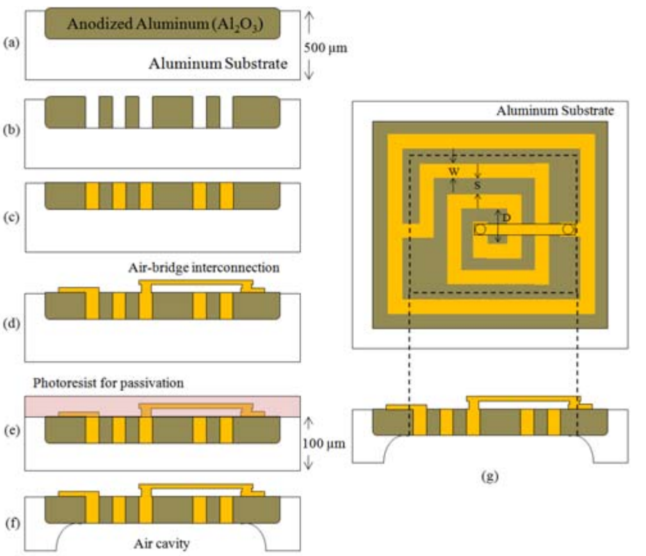

Fig. 1 Proposed structure and fabrication process of substrate-embedded spiral inductor on anodized aluminum substrate

2. High-Q Embedded Spiral Inductor on Anodized Aluminum Substrate

Fabrication of Substrate-Embedded Spiral Inductor

The fabrication process of high-Q substrate-embedded spiral inductor on anodized aluminum substrate is schematically described in Fig. 1. Low-cost, industry-grade 500 μm-thick aluminium sheets of 99.5% purity are grinded and polished to have improved surface roughness of about 80 Å (RMS value), which is sufficient to be used in the following anodizing, micromachining, and thin-film process. One side of the aluminum substrate with mirror-like surface is anodized in 5% oxalic acid at 20℃ for 40 minutes to obtain an anodized aluminum (Al_2O_3) layer of 50 μm thickness (see Fig. 1(a)), that corresponds to the line thickness of the embedded spiral inductor. Relative dielectric constant of anodized aluminum is 6.8. Various patterns of spiral inductor are formed on anodized aluminum layer through the photolithography process. The wet-etching of the anodized aluminum layer is then carried on by dipping the patterned substrate into 5% oxalic acid solution at 75℃ for 70 minutes to reveal the inductor pattern by remaining residue

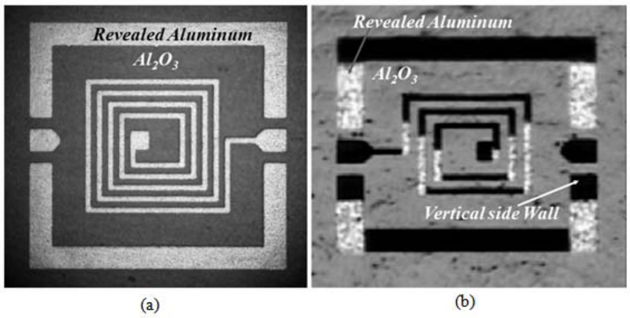

Fig. 2 Photographs of signal lines formed on anodized aluminum layer by chemical wet-etching process. (a) The front view, (b) The oblique view of the same object

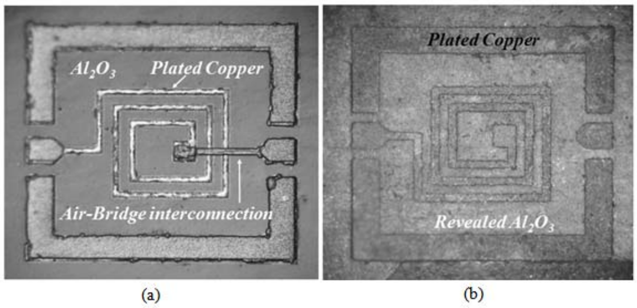

Fig. 3 Photographs of fabricated substrate-embedded inductor (Number of turns=2.5, inner diameter=200 μm, line space=40 μm, line width=20 μm) (a) Top view, (b) Bottom view

of the signal line as described in Fig. 1(b). Fig. 2 shows the anodized aluminum layer with spiral inductor pattern which vertically stands after the wet-etching process. Dark areas in Fig. 2(b) represent shadows caused by 50 μm height difference between aluminum layer and vertically standing anodized aluminum layer. Etched areas are filled with copper by electroplating process forming a uniform 50 μm-thick copper signal line. And then polishing process is followed to flatten the rugged surface of the electroplated copper (see Fig. 1(c)). A conventional air-bridge process is followed to make interconnection between the end of the signal line and an outer pad as shown in Fig. 1(d). Backside of the anodized aluminum substrate is grinded into thickness of 100 μm to shorten the time required for the following backside etching process. Backside is patterned to open the area under the embedded signal line, and the patterned area of the backside is etched by dipping into hydrochloric acid to form an air-cavity, which contributes to improve Q-factor. Fig. 3(a) and (b) represent respectively top and bottom view of the fabricated spiral inductor with 2.5 turns, 200 μm inner diameter, 40 μm line space, and 20 μm line width.

Measurement

The on-wafer S-parameter measurement ranging from 0.2 GHz to 20 GHz is performed using Anritsu 37397D vector network analyzer. Measured spiral inductors with different line spaces commonly have line thickness of 50 μm, signal line width of 20 μm, 2.5 turns, and inner diameter of 220 μm. Q-factor and values of series inductance are calculated by :

$$Q_{ind} = \frac{\mathrm{Im}\{Z_{in}\}}{\mathrm{Re}\{Z_{in}\}} = -\frac{\mathrm{Im}\{Y11\}}{\mathrm{Re}\{Y11\}} \qquad (1)$$

$$L_s(f) = \mathrm{Im}\left(-\frac{1}{Y21}\right)/2\pi f \qquad (2)$$

Fig. 5 shows Q factor and series inductance with line space variation (S) from 30 μm to 50 μm. An inductor with 50 μm line space has the highest maximum Q value of 82 at 4 GHz while its series inductance is 2.6 nH at 2 GHz and self-resonant frequency is around 10 GHz. As the line space increases, the Q value increases due to the reduction of parasitic capacitance between the signal lines. RF performance of the fabricated inductors is summarized in Table I.

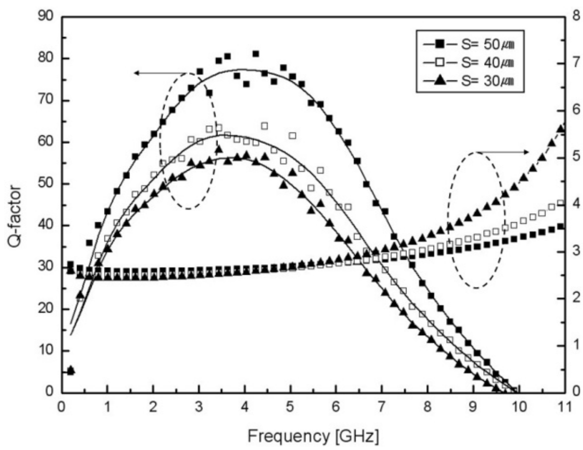

Fig. 4 Measured Q-factor and effective inductance of spiral inductors with line space variation. (Number of turns=2.5, inner diameter=200 μm, line width=20 μm)

Table I Performance of the substrate-embedded inductor

Line Space	L [nH] at 2GHz	Q at 2GHz	Q max	SRF [GHz]
S=30 μm	2.45	47.10	58 at 3.3 GHz	10
S=40 μm	2.5	51.88	64 at 3.3 GHz	10
S=50 μm	2.59	61.53	83 at 4.2 GHz	10

3. Conclusions

We proposed a new fabrication process to make high-Q inductor on low-cost anodized aluminum substrate. High aspect ratio of signal line is easily fabricated using chemical wet-etching property of anodized aluminum without any special treatment of photolithography. The proposed fabrication method is very simple and cost-effective for making thick metal structure. The fabricated inductor showed high Q-factor of over 80 in GHz frequency ranges. In comparison with other micro-machined integrated inductor, this type of inductor is mechanically more stable due to Al_2O_3 layer and high throughput. These works demonstrate that integrated passive devices (IPDs) on anodized aluminum substrate have a potential to compete with other conventional technologies like silicon technology, LTCC technology, etc.

Acknowledgements

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