Si-based electromagnetic noise suppressors integrated with a magnetic thin film

Sohn Jaecheon, Han S. H., Yamaguchi Masahiro, Lim S. H.

Journal or publication title: Applied Physics Letters
Volume: 90
Number: 14
Page range: 143520
Year: 2007
URL: http://hdl.handle.net/10097/51578
doi: 10.1063/1.2719681
Si-based electromagnetic noise suppressors integrated with a magnetic thin film

Jaecheon Sohn and S. H. Han
Nano Device Research Center, Korea Institute of Science and Technology, Seoul 130-650, Korea

Masahiro Yamaguchi
Department of Electrical and Communication Engineering, Tohoku University, Sendai 980-8579, Japan

S. H. Lim
Department of Materials Science and Engineering, Korea University, Seoul 136-713, Korea

(Received 3 January 2007; accepted 4 March 2007; published online 6 April 2007)

Electromagnetic noise suppressors on Cu transmission lines and oxidized Si substrate integrated with a SiO$_2$ dielectric and a Co–Fe–Al–O magnetic layer are presented. Extremely large signal attenuation is achieved (−90 dB at 20 GHz) while the signal reflection is relatively small, being below −10 dB. These characteristics are attributed to the distributed capacitance ($C$) formed by the Cu and the oxidized Si substrate and the Cu/SiO$_2$/Co–Fe–Al–O and the distributed inductance ($L$) due to the magnetic thin film. The main loss mechanism is the $L$-$C$ resonance and this emphasizes the role of the magnetic thin film providing the inductance. © 2007 American Institute of Physics [DOI: 10.1063/1.2719681]
magnetic film with the composition of Co_{41}Fe_{38}Al_{13}O_{8} (in at.%) was deposited by rf magnetron sputtering under a static magnetic field of 1 kOe to form an induced anisotropy.\textsuperscript{8,9} For the measurements, two ground-signalground pin-type wafer probes were in mechanical contact with both ends of the coplanar waveguide (CPW) transmission line. The $S$ parameters ($S_{11}$ and $S_{21}$) were measured using a HP 8720D network analyzer at frequencies ranging from 0.1 to 20 GHz.

The Co_{41}Fe_{38}Al_{13}O_{8} nanogranular thin film exhibits excellent soft magnetic properties at high frequencies and the important properties are summarized as follows: a electrical resistivity ($\rho$) of 374 $\mu$Ω cm, an anisotropy field ($H_A$) of 50 Oe, a hard axis coercivity of 1.25 Oe, a saturation magnetization ($4\pi M_S$) of 12.9 kG, and a resonance frequency ($f_R$) of 2.24 GHz.

Figures 2(a) and 2(b), respectively, show the frequency dependency of the transmitted ($S_{21}$) and reflected ($S_{11}$) scattering parameters for the bare CPW transmission lines with lengths of 2, 5, 10, and 15 mm. Geometrically, the bare structure based on a Si substrate is similar to that based on a glass substrate\textsuperscript{1–6} in that there were no dielectric layers on the transmission line. However, in the viewpoint of wave transmission, a large difference is expected due to the existence of a distributed inductance component in the Si-based device formed by the Cu transmission line/SiO$_2$/Si substrate.

It is seen from Fig. 2(a) that, for a given transmission line length ($l$), the signal attenuation increases monotonically with increasing frequency, except for a small plateau near 2 GHz at $l$=10 and 15 mm. At a given frequency, the attenuation increases with increasing transmission line length, which is more obvious at higher frequencies. At the lowest measured frequency, 100 MHz, there was no obvious difference in the signal attenuation regardless of the length, but differences begin to appear at 200 MHz. At $l$=2 mm, only a moderate frequency dependence of the signal attenuation is observed over the entire frequency range. However, at longer lengths, a rather steep signal attenuation begins to occur at certain frequencies: 6 GHz at $l$=5 mm and 2–3 GHz at $l$=10 and 15 mm. The magnitudes of the signal attenuation at the highest measured frequency of 20 GHz are ~7.5 dB at $l$=2 mm, ~16 dB at $l$=5 mm, ~33.5 dB at $l$=10 mm, and ~50 dB at $l$=15 mm. This frequency dependence of the signal attenuation showing a monotonic behavior indicates the absence of resonance in the measured frequency range, possibly due to the absence or a small magnitude of the distributed inductance component in the bare structure. The amount of reflected signal ($S_{11}$), as shown in Fig. 2(b), is relatively small, being less than ~15 dB in all cases. At low frequencies, the magnitude of the reflected signal increases progressively with increasing length. However, no obvious tendency is seen at high frequencies because of the appearance of sharp minima (dips) in $S_{11}$. These dips are caused by dimensional resonance losses, which occur when the length of the transmission line is an integer multiple of the half guided wavelength of the electromagnetic wave.\textsuperscript{10–13}

It is of interest to compare the results for the bare transmission lines based on the Si substrate with those for the bare structure based on the glass substrate reported previously.\textsuperscript{5,6} In the case of the bare structure based on the glass substrate, the attenuation of the transmitted signal is very small over the whole frequency range (at low frequencies, in particular), the highest being ~2.3 dB at the highest frequency of 20 GHz and the longest length of 15 mm.\textsuperscript{5,6} In addition, the amount of reflected signal is also very small, being less than ~30 dB in all cases.\textsuperscript{5,6} The main reason for the large difference can be the formation of a distributed capacitor even in the bare transmission line of the Si-based device. No capacitor component is expected in the glass-based bare structure where the Cu transmission line is on top of the dielectric glass. In this case, the scattering parameters and power loss can be determined mainly by the eddy current losses with a minor contribution from the distributed inductance of the Cu transmission line itself.

The dielectric and magnetic thin films were subsequently coated to the bare structure to form complete integrated devices. Figures 3(a) and 3(b) show the frequency dependencies of $S_{21}$ and $S_{11}$, respectively. The thicknesses of the SiO$_2$ and Co–Fe–Al–O thin films are 0.1 and 1 $\mu$m, respectively. The length of the transmission line was fixed to 15 mm (the longest), while the width of the magnetic thin film was varied from 50 to 2000 $\mu$m. With the additional dielectric and magnetic layers on top of the transmission line, another distributed capacitor can be formed by the trilayer structure, which is the Cu transmission line/SiO$_2$ dielectric layer/Co–Fe–Al–O magnetic thin film. Furthermore, the magnetic thin film can form an additional component in a distributed inductor. This additional inductance component due to the magnetic thin film is of significant importance in explaining the large difference of the results shown in Figs. 2(a) and 2(b) for the bare structure and in Figs. 3(a) and 3(b) for the full devices. This is because the transmission and reflection characteristics of the latter devices are greatly affected by the
of signal attenuation is probably highest for rf noise suppressors with similar lateral dimensions. As shown in Fig. 3(b), the amount of signal reflection increases with increasing width, which is a behavior similar to those observed previously. In all cases, the value of $S_{11}$ are below $-10$ dB over the whole frequency band, suggesting that the input signal distortion due to the reflected signals may not be serious when used as noise suppressors.

The Si-based CPW transmission lines integrated with a $\mathrm{SiO}_2$ dielectric and a nanogranular Co–Fe–Al–O magnetic thin film are found to show very good noise attenuation characteristics. The value of $S_{21}$ is as low as $-90$ dB at the highest measured frequency of 20 GHz. This level of signal attenuation is probably among the highest for the rf noise suppressors with similar lateral dimensions. The signal reflection is relatively small, being below $-10$ dB. Three important components can be identified for the good characteristics: (1) the distributed capacitance formed by the Cu transmission line/$\mathrm{SiO}_2$ dielectric layer/Co–Fe–Al–O magnetic thin film, (2) the distributed inductance due to the magnetic thin film, and (3) the additional distributed capacitance formed by the Cu transmission line/$\mathrm{SiO}_2$/$\mathrm{Si}$ substrate. It is noted that the first two components already exist in the usual glass-based devices where the main loss mechanism is the $L$–$C$ resonance. Considering this, the extremely large signal attenuation of the Si-based devices results from the third component, the additional distributed capacitance formed by the Cu transmission line/$\mathrm{SiO}_2$/$\mathrm{Si}$ substrate. It is believed that these noise suppressors based on the Si substrate, with their good signal attenuation and reflection characteristics, will be an important step in the realization of MMIC noise suppressors.

This work was supported by the Korea Science and Engineering Foundation (KOSEF) through the National Research Laboratory program funded by the Korean Ministry of Science and Technology (Project No. M10600000198-06J0000-19810).