行政院國家科學委員會補助專題研究計畫 □成果報告 ■期中進度報告

（計畫名稱）

矽 VLSI 之射頻光學無線內接線 (1/3)

計畫類別：□個別型計畫 ■整合型計畫
計畫編號：NSC 91－2215－E－009－038－
執行期間：91年8月1日至92年7月31日

計畫主持人：荊鳳德
共同主持人：
計畫參與人員：

成果報告類型(依經費核定清單規定繳交)：□精簡報告 ■完整報告

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執行單位：交通大學電子所

中華民國九十二年二月二十五日

一、 中文摘要

本計畫主要研究無線高頻內接線在矽基板上之可行性。使用我們的佈植方法，可用於高頻無線傳輸之矽積體微小天線的訊號損耗在20 GHz時可達到非常低的值。這是由於經過高能粒子佈植製程之矽基板，其阻值已非常高，能有效斷絕訊號損失之故。

關鍵詞: 無線內接線，矽積體天線

二、英文摘要

High performance antenna has been realized on proton-implanted Si with $10^6\ \Omega$-cm resistivity. Sharp antenna resonance and low loss up to 20GHz are observed indicating the excellent antenna quality. In contrast, very poor antenna characteristics are found on conventional oxide-isolated Si because of the lossy substrate.

關鍵詞: Wireless interconnect, Si integrated antenna

三、報告內容：

甲、前言：

While wireless communication has grown rapidly in the recent few years, the future generation of wireless communication requires high integration level for lowering down the manufacture cost. The integrated on-chip antenna has attracted much attention for wireless communication and chip level wireless interconnect because of its capability of integration with the signal processing circuits. The potential of integrated antenna becomes even higher as increasing operation frequency because of the reduced size (~λ/4) at higher frequencies (1)-(2). However, one of challenges for on-chip antennas is the large transmission loss due to the low resistivity (10Ω-cm) Si. This is the fundamental limitation of Si operated at RF frequency and becomes more serious as the frequency increases. In order to overcome this problem, we have developed the $10^6\ \Omega$-cm resistivity Si, which is close to semi-insulating GaAs (3)-(4). This 1 MΩ-cm resistivity Si is selectively formed by proton implantation and has negligible degradation on gate oxide integrity. Further, the 1 MΩ-cm resistivity can be maintained above 400^{o}C that is suitable for VLSI backend process integration (5). In this paper, we have successfully demonstrated high quality antennas on proton-implanted Si. Sharp antenna resonance up to 20GHz is measured with small bandwidth less than 0.5 GHz that is even better than Si-on-quartz (SOQ). For comparison, very poor antenna resonance is found on conventional oxide-isolated Si because of the lossy substrate.

乙、研究方法

We have designed planar inverted-F antennas (PIFA) and meander antennas on standard Si with resistivity of 10 Ω-cm, SOQ with top 250 nm Si, and proton-implanted Si with resistivity of 10^6 Ω-cm. A thick 1.5 μm thermal oxide was further grown on standard Si to decrease the substrate loss. Then the antenna structure is formed on the different substrates using 4 μm thick Al. The PIFA and meander antennas are the most commonly used antennas and the former is already incorporated into the cellular phones in the market. The integrated PIFA in the handsets not only strengthens the compression-resist ability but also reduces the power absorption into the head (6). Generally, the total length of the meander antenna is about λ/4 (7). However, the design configuration varies with the space between each finger and the width of the antenna arm.

Fig. 1 shows the antenna configurations including one meander 10 GHz and two PIFA, which is designed to resonate at 10 GHz and 5.8 GHz, respectively. Each kind of antenna is sized below 5 mm×10 mm cm depending on the resonant frequency (quarter a wavelength), substrate dielectric constant and substrate conductivity. The antennas were designed by IE3D and a high frequency structure simulator (HFSS) with a 50 Ω input impedance. A coplanar transmission line with 150 μm GSG probe pitch is used for RF impedance matching. Standard de-embedding procedure (8) is performed only on return loss measurement, while other antenna characteristics are measured without such de-embedding. The return loss of antenna is measured by HP8510C Network analyzer, while the radiation pattern is obtained using an antenna measurement systems composed of HP85301C, network analyzer and frequency sweeper.

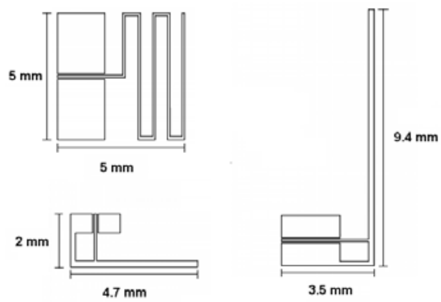

Fig. 1

丙、 結果與討論（結論與建議）

(A) Return loss:

Fig. 2 shows the measured return loss of meander antennas designed at 10 GHz. The antenna on standard Si with thick isolation oxide is so lossy over the whole frequency range, while SOQ and proton-implanted Si show very low loss up to 20GHz and resonance at 16 GHz and 10 GHz, respectively. Beside the primary resonance peak, another sharp second harmonic resonance at 20GHz is observed that indicates the possibility to form on-chip antenna at this high frequency. Figs. 3 and 4 are the return loss of PIFA designed at 10 GHz and 5.8 GHz, respectively. Sharp resonance peaks are obtained for SOQ and proton-implanted Si, but the large conduction loss for standard SiO_2/Si prohibits

its antenna application. The bandwidth of meander antennas on proton-implanted Si is less than 2% at 10 GHz, which has a value about 200 MHz and is suitable for the narrow bandwidth applications. From the shifted resonant frequency of proton-implanted Si, the PIFA is more sensitive to Si dielectric constant that is changed by the implantation.

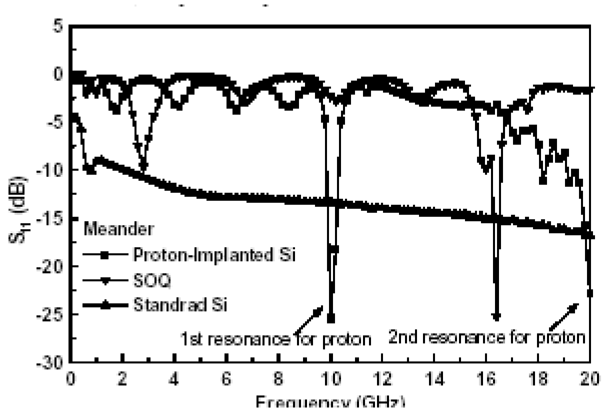

Fig. 2

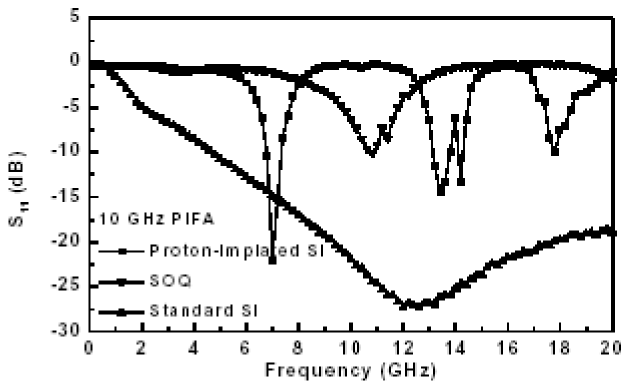

Fig. 3

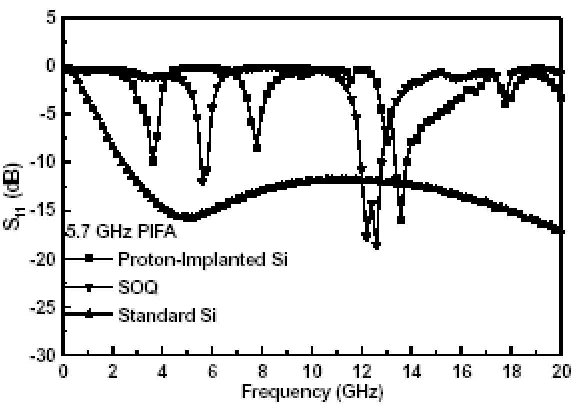

Fig. 4

To understand the huge loss for antennas on SiO_2/Si, we have further measured the transmission line loss. Fig. 5 shows the insertion loss of 1mm long coplanar transmission lines on various substrates. The power loss of standard SiO_2/Si is the worst and increases as frequency increase, while the proton-implanted Si has the lowest insertion loss and less frequency independence that is consistent with the lowest return loss in antenna.

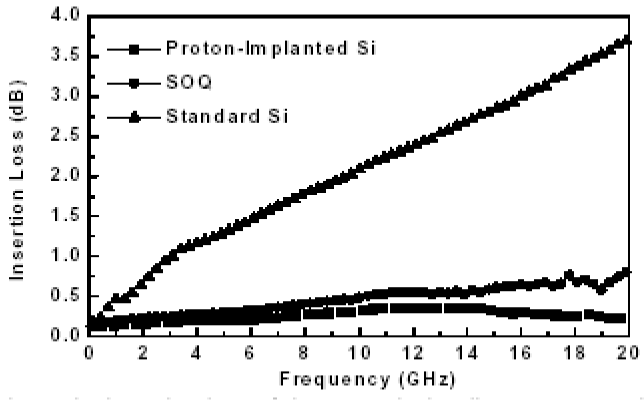

Fig. 5

(b) Loss mechanism and modeling:

We have further analyzed the substrate effects on antenna loss using the equivalent circuit model shown in Figs. 6 and 7. These models combine the antenna with a coplanar transmission line, in which the shunt resistance and capacitance to ground are used to model the substrate loss. Figs. 8, 9 and 10 are the simulated and measured antenna return loss for various type antennas. Good matching of peak frequency and bandwidth are obtained at the first resonance for all kinds of antennas that suggest the excellent accuracy of these models. The extracted substrate shunt resistances from the matched models are shown in Fig. 11. Large shunt resistance >10^7 Ω are observed on proton-implanted Si and SOQ, which give a nearly open circuit to ground. However, standard Si has a small shunt resistance of only 10^2 Ω that explains the poor antenna characteristic. The reason why the proton-implanted Si has even higher shunt resistance than SOQ is due to the low resistivity at the top 250nm Si of SOQ.

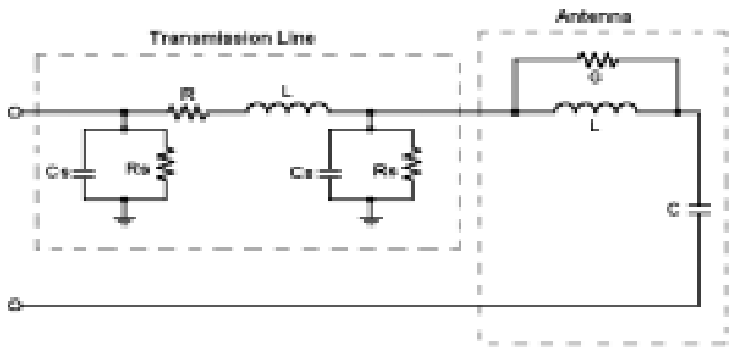

Fig. 6

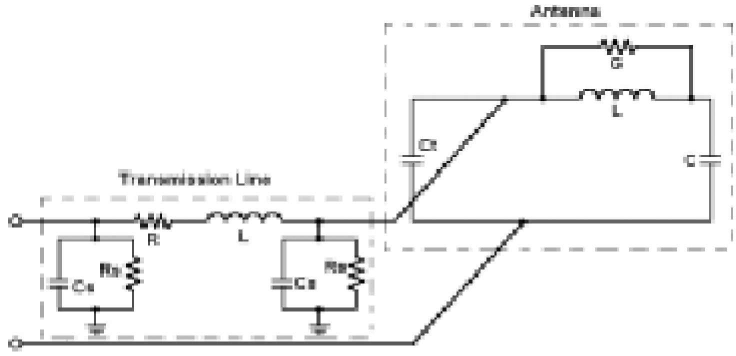

Fig. 7

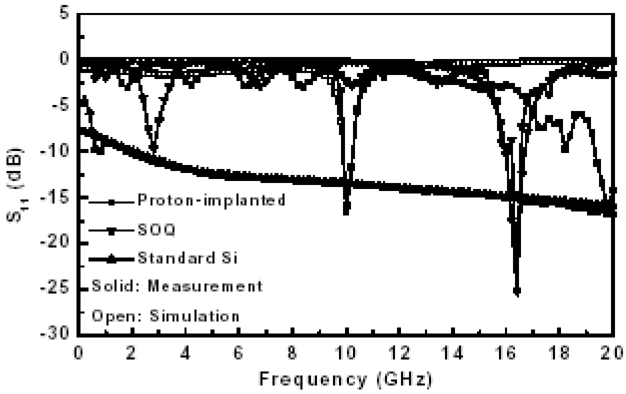

Fig. 8

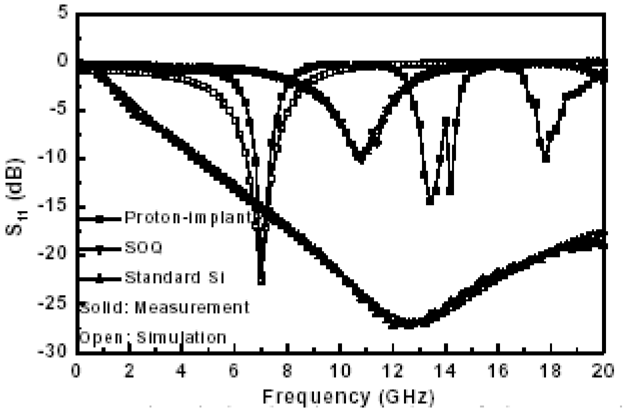

Fig. 9

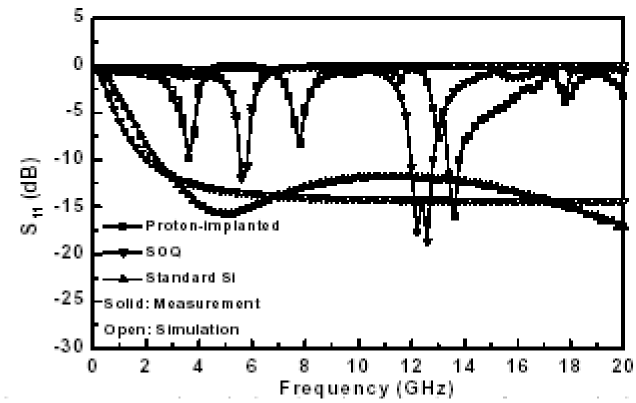

Fig. 10

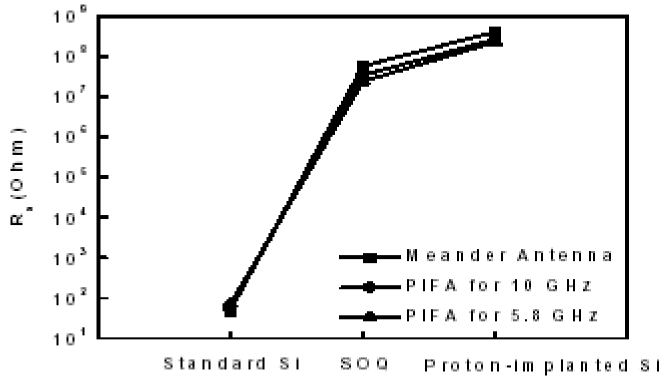

Fig. 11

三、已有論文發表附錄

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五、計畫成果自評

We have compared the integrated meander and PIFA antennas on oxide isolated standard Si, SOQ and proton-implanted Si. Among them, he on-chip antenna on proton implanted Si has the best radiation pattern, lowest return loss and sharpest resonance. In contrast, almost no antenna characteristic is found on conventional oxide-isolated Si. Sharp antenna resonance and low loss up to 20 GHz are observed on proton-implanted Si that indicates the excellent antenna quality.