行政院國家科學委員會專題研究計畫　期中進度報告

矽 VLSI 之射頻與光學無線內接線(2/3)

計畫類別：個別型計畫
計畫編號：NSC92-2215-E-009-017-
執行期間：92 年 08 月 01 日至 93 年 07 月 31 日
執行單位：國立交通大學電子工程學系

計畫主持人：荊鳳德

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中　華　民　國 93 年 5 月 10 日

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）

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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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中　華　民　國　九十三　年　五　月　　　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。發光於 1.3um 波段的穿遂二極體可由矽鍺成長於矽基板上，並在閘極端堆疊週期性的錫摻雜於氧化銦以及氧化鋁介電層之結構來完成，而發光的能隙是較小於矽能階，故可避免光子由矽基板而被吸收。另一優勢，因閘極多晶矽利用此結構可透射出發光光源，可整合於現今金氧半電晶體之中，大幅提昇光電整合的機會，而在鍺的摻雜量從 0.3 到 0.4，只會有些微降低其發光的效率。

二、英文摘要

We have fabricated Sn:In_2O_3 (ITO)/Al_2O_3 dielectric on $Si_{1-x}Ge_x$/Si MOS tunnel diodes which emit light at around 1.3 μm, for x = 0.7. The emitted photon energy is smaller than the bandgap energy of Si, thus avoiding strong light absorption by the Si substrate. The optical device structure is compatible with that of a MOSFET, since a conventional doped poly-Si gate electrode will be transparent to the emitted light. Increasing the Ge composition from 0.3 to 0.4 only slightly decreases the light emitting efficiency.

Key Words: electroluminescence, SiGe, LED, Al_2O_3, light.

三、報告內容

甲、前言

The backend RC delay is one of the main challenges in VLSI technology. Advanced backend processes incorporating copper and low-K dielectrics, for instance, do not eliminate concerns about the AC power consumption and the RC delay in high performance circuits. Optical interconnects have been proposed and are considered to be a potential option for replacing the conductor/dielectric system for global interconnects [1]. However, the lack of a Si-based light source is the main bottleneck for this technology, in part due to the indirect bandgap in Si. A Si-based light-emitting device (LED) would also enable inter-chip optical wireless communications as well and optical fiber DWDM applications [2]. Recently MOS tunnel diodes [3]-[5] have been proposed as a possible candidate for Si-based LEDs, because of their good performance and inherit integration capability with MOSFETs and current VLSI technology. We have previously shown that the use of a high-k gate dielectric [6]-[7] in a MOS tunnel diode can improve the light emission efficiency and reliability due to the strong quantum confinement for providing additional momentum in indirect bandgap Si [5]. However, the emitted photon energy is larger than the energy bandgap of Si [3], [5], which makes absorption in the Si substrate an issue. To overcome this problem, we have developed an Sn:In_2O_3 (ITO)/Al_2O_3 dielectric on $Si_{1-x}Ge_x$/Si [8]-[14] tunnel diode which has its emitted photon energy below the bandgap energy of Si. Combined with the advantage of a high-k gate dielectric, the

$ITO/Al_2O_3/Si_{0.3}Ge_{0.7}$ device, with light emission in the ~1.3 μm range, shows great potential for optical interconnects and wireless communications.

乙、研究方法

Standard 4-inch (100) p-type Si substrates were used in this study. Layers of ~20 nm $Si_{0.3}Ge_{0.7}$ were formed on the Si wafers by solid phase-epitaxy (SPE), first depositing amorphous Ge on the native-oxide desorbed Si surface in a modified MBE system under high vacuum, followed by an RTA at 900^{o}C to form SiGe by SPE [8]. The advantage of SPE compared with UHVCVD or direct MBE grown SiGe is the high temperature stability, smooth surface and high MOSFET device performance [8]-[14]. The low electrical defect in SPE formed SiGe can also evidenced from very small interface trap density close to Si [9]-[11]. Then, 3 periods of 2nm-ITO/1.5nm -Al_2O_3 superlattice (SL) gate dielectrics [5] were formed on the $Si_{0.3}Ge_{0.7}$. Top contacts were transparent ITO, 0.2 μm thick, which were subsequently sintered at 450^{o}C in N_2 ambient, to improve the ITO quality. For comparison, $ITO/Al_2O_3/Si_{1-x}Ge_x$ SL tunnel diodes with total 30 nm thickness and Ge compositions of 0.2 and 0.4 were also fabricated. Fig. 1 shows the cross-section view of fabricated device. The light emission was measured using a Hamamatsu PHEMOS-1000 light detection system used in Si IC industry and equipped with CCD camera for IR image. A conventional photo-multiplier tube was used to detect the emitted at energies > 1.1 eV, while an InGaAs detector was used at less than 1.1 eV.

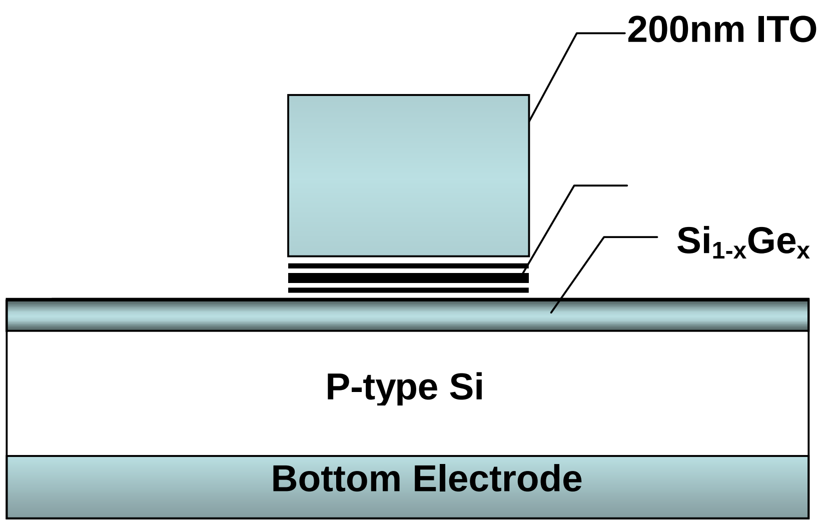


Fig.1. The cross-section view of $ITO/Al_2O_3/Si_{0.3}Ge_{0.7}$ SL MOS tunnel diodes.

丙、結果與討論（結論與建議）

Fig. 2 shows the light emission spectra and light emission picture (Ig = -6mA) of ITO/Al_2O_3/$Si_{0.3}Ge_{0.7}$ SL tunnel diodes. The image shows a uniform light emission from the tunnel diode with strong light emission. The emitted wavelength range, from 1.1~1.4 μm, covers the important wavelength of 1.3 μm used for optical fiber communication. The emitted photon energy increases with increasing gate voltage, which is similar to the Si MOS tunnel diode [5]. Since the emitted photon energy is less than the bandgap energy of Si, the optical loss through Si substrate absorption is reduced. Therefore, it would make such devices compatible with MOSFETs and they could be integrated into current VLSI.

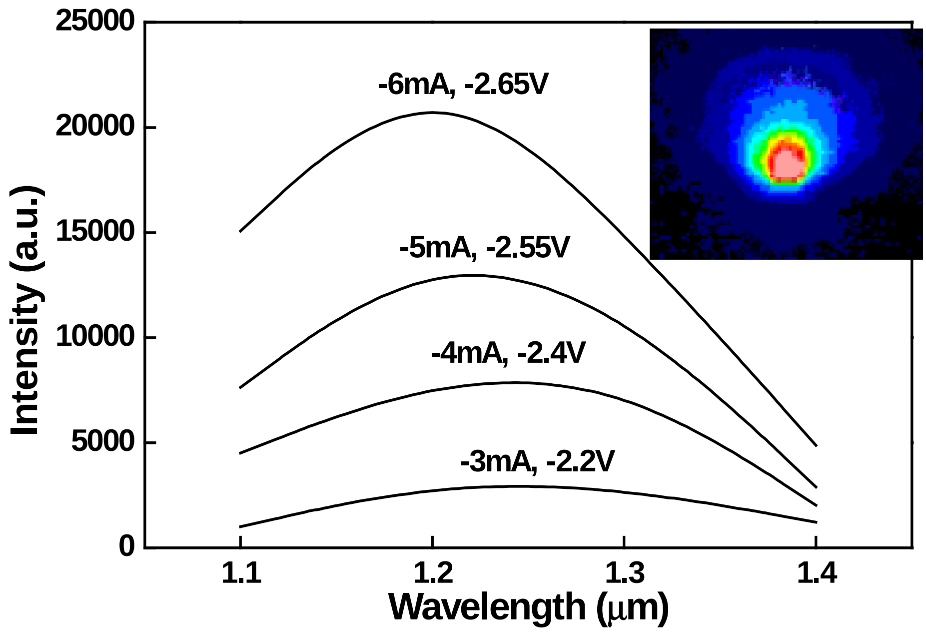
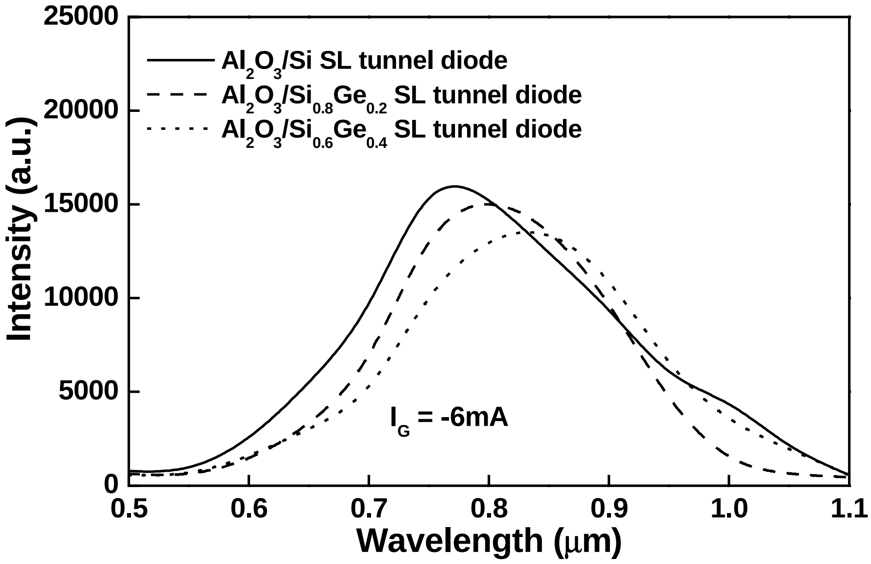
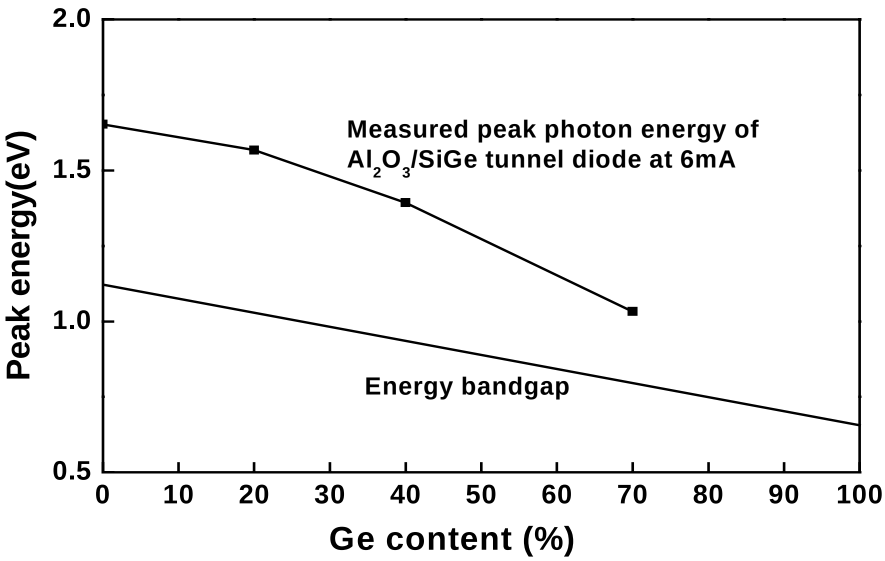


Fig.2 The electroluminescence spectra of ITO/Al_2O_3/$Si_{0.3}Ge_{0.7}$ SL tunnel diodes with different injection current levels. The insertion figure is the picture of light emission at -6 mA.

To investigate whether the light emission originates from the SiGe quantum well, we have also measured the emission in ITO/Al_2O_3/$Si_{1-x}Ge_x$ tunnel diodes with different Ge compositions of 0, 0.2 and 0.4. Figs. 3(a) and 3(b) show the variation of the measured spectra and peak photon energy with different Ge contents. The peak photon energy and spectra shift to lower energy with increasing Ge composition. This excludes the possibility that the electroluminescence is generated from the gate dielectric, because it is the same for all devices. The peak photon energy in MOS tunnel diode is always greater than the linear interpolated energy bandgap - this is consistent with our previous result [5]. The larger photon energy in MOS tunnel diode can be interpreted as due to hole quantization effect in the accumulation layer of the p-Si surface [14]. Due to hole quantization [15], the effective energy bandgap from conduction to valence band optical transition will be increased compared to the bulk SiGe energy bandgap. The energy increment becomes larger at higher gate voltage because of stronger hole quantum confinement, which is consistent with the peak energy blue shift data in Fig. 2. The strong confinement is the merit of high-k gate dielectric to achieve a small inversion layer thickness [5] and high current drive [6].



(a)



(b)

Fig.3. Comparisons of (a) electroluminescence spectra and (b) the peak light emission energy of ITO/Al_2O_3/$Si_{1-x}Ge_x$ (x=0, 0.2, and 0.4) SL tunnel diodes at –6 mA injection current.

Since the light emission efficiency is an important parameter for optical devices, we compare, in Fig. 4, this parameter for ITO/Al_2O_3/$Si_{1-x}Ge_x$ tunnel diodes with different Ge composition of 0, 0.2 and 0.4 under similar conditions with the same detection system. We can not compare this efficiency data with that of the ITO/Al_2O_3/ $Si_{0.3}Ge_{0.7}$ devices because a different photo detector must be used. Although the luminescence efficiency decreases with increasing Ge concentration, the magnitude of the change, when the Ge composition is increased to 0.4, is not serious. This result is likely due to the excellent quality of the SiGe, which was deposited at the high epitaxy temperature of 900^{o}C. We note that in III-V semiconductors high growth temperatures can improve the luminescence efficiency by more than one order of magnitude [16]-[18] and is the primary material epitaxy parameter for optical devices.

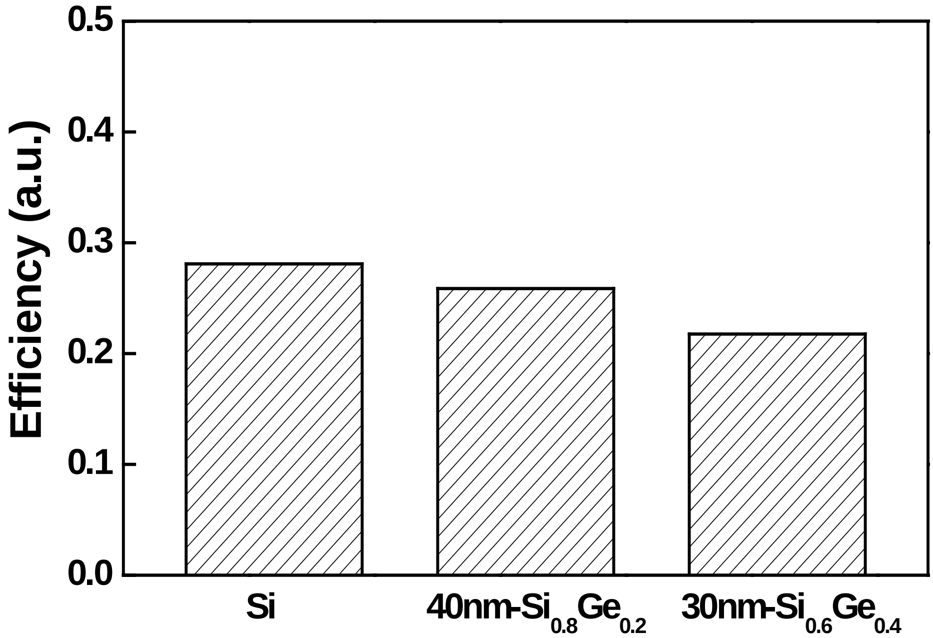


Fig.4. Emission efficiency comparison for ITO/Al_2O_3/$Si_{1-x}Ge_x$ (x=0, 0.2, and 0.4) SL tunnel diodes at –6 mA injection current.

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五、計畫成果自評

We have fabricated ITO/Al_2O_3/$Si_{0.3}Ge_{0.7}$ MOS tunnel diodes and demonstrated emission ~1.3 μm. The excellent optical properties, together with a device structure similar to that of MOSFET, suggest that these devices may enable the development of Si-based technology for optical interconnects and wireless communication.