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Feasibility of Fabrication of Heteroepitaxial Ge_x Si_{1-x}/Si(111) structure by Pulsed Nd: YAG Laser

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Abstract

Heteroepitaxial Ge_x Si_{1-x} alloy layers have been formed by 10 ms and 300 μs laser pulse induced mixing of pure germanium films and Si(111) substrates where Ge films of thickness (500-1250) Å are thermally evaporated onto Si(111) under vacuum pressure $\sim 10^{-5}$ Torr. The near surface of the sample then undergoes rapid melting and regrowth processes during each pulse from a free running Nd; YAG laser.

The alloy layers are (4.6-6.5) μm thick and have a Ge fraction of x=6-8.2 %.

1. Introduction

It is well known that Si-Ge is a very promising system for producing junctions that can be used for the modulation of doped field effect transistors which are significantly faster than silicon [1]. To date, Ge_x Si_{1-x} layers have been grown by techniques of molecular beam epitaxy (MBE) or chemical vapour deposition (CVD) which require low levels of interfacial contamination and precise control of the growth temperature in order to produce defect-free strained layers [2].

Alternative methods of producing Ge_x Si_{1-x} crystalline layers have been suggested, including laser mixing of pure germanium amorphous film deposited on a silicon substrate [3]. The advantages of this method are (i) the utlra-short time scale that a sample is exposed to elevated temperatures, (ii) the spatially selective nature of the process, (111) its flexibility of allowing several different processing conditions on one wafer, and (iv) the availability of reliable process control [4].

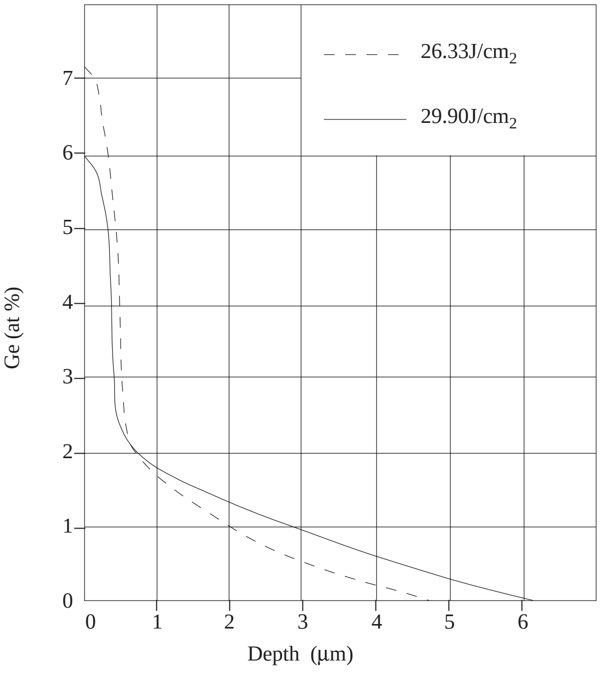
The first objective of the present work is to demonstrate a pulsed laser mixing technique to grow heteroepitaxial Ge_x Si_{1-x} layers. Second, the structure of laser processed regions is investigated.

2. Experiment

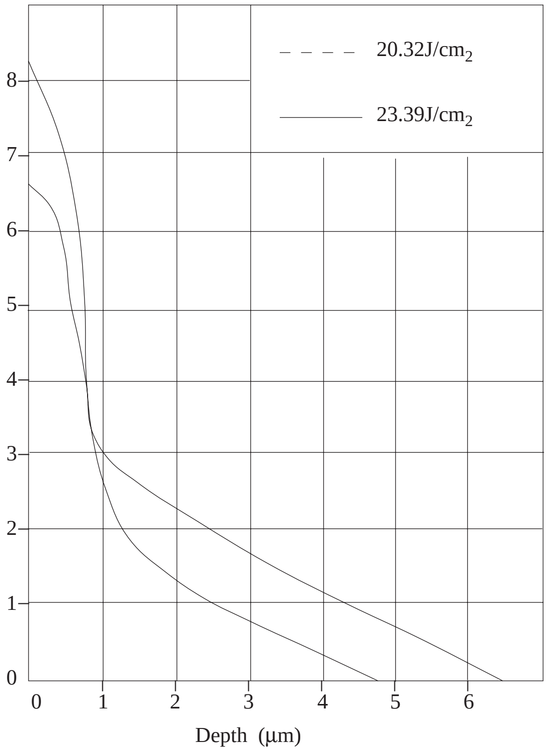
The details of processing are as follows; Si(111) substrate, are boron doped to electrical resistivity of 1.5 Ω.cm. Then they are dipped in 50;1 (volume) HF acid to remove native oxides on the surface, and immediately loaded into a thermal evaporation system (Balzer BAE 370) which is subsequently evacuated to pressure $\sim 10^{-5}$ Torr. Pure germanium (99.999%) is deposited onto the Si substrate with thickness ranging from 500 to 1250 Å. Following the evaporation process, each sample is transferred to a pulsed laser apparatus. The samples were irradiated using a single pulse of a Nd; YAG laser, with the pulse approximately gaussian in time ($\mathrm{TEM}_{\sim 00}$). The energy required to initiate the melting is measured via scattering using a He-Ne laser, as shown in the schematic diagram presented in [5]. Energy dispersive spectroscopy (EDS) system is used to determine the alloy layer thickness and (x) value. To investigate the microstructure of laser treated regions a scanning electron microscope (SEM) was used.

3. Results and Discussion

Figure 1 shows the concentration vs depth profile for 1250 Å Ge/Si samples formed by different pulse laser energy densities with different pulse durations. The germanium distributions prossesses several features in common.



(a)



(b)

Figure 1. Ge concentration profiles of sample 1250 Å Ge/Si (111) irradiated with different laser conditions A- 10 ms B- 300 μs.

First, Ge is not strongly rejected from the growing crystal to the free surface, as it is common for impurities having very low distribution coefficient K (k=C_s/C_1) [6]. The peak of germanium concentration is, however, always located at the vicinty of the surface, as might be expected for the case of moderate segregation. Ge and Si form a continuous series of solid solutions for which the equilibrium distribution coefficient lies in the range from 0.3 to 0.5, depending upon composition [7]. Evidently, solute trapping does not greatly increase the interfacial value of K for these concentrated alloys, even through it causes a remarkable increase in K value for dilute substitutional impurities [7,8].

All of the Ge profiles have two distinct regions; an exponential rise in Ge concentration that is followed at shallower depths by a linear increase to the surface. The exponential depth dependence of germanium concentration is just the distribution expected for a multiply melted alloy. The departure of the distribution from exponential form may be due to cellular crystal growth.

It appears that a pronounced modification is introduced in the germanium profile distribution when the pulse energy is increased. The diffusion depth is increased by a factor of 1.3 and 1.43 for pulse durations 10 ms and 300 μs, respectively.

The first area processed at energy density of 26.33 J/cm^2 and pulse duration of 10 ms formed an alloy layer of $Ge_{0.07}Si_{0.93}$4.7 μm thick. Figure 2 shows the SEM micrograph of a laser processed region. The second area, which was irradiated with higher energy density (29.9 J/cm^2), exhibited an alloy of $Ge_{0.06}Si_{0.94}$ 6.2 μ thick. Alloy layers of similar quality and smaller Ge fraction values have been obtained from the intermixing of 500-1000 Å Ge layers on Si(111) substrate as shown in Figure 3.

Figure 2. SEM micrograph of sample 1250 Å Ge/Si irradiated with 26.33 J/cm^2 of 10 ms pulse duration

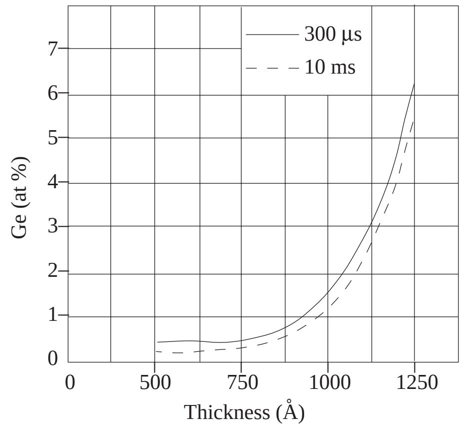


Figure 3. Ge concentration vs initail Ge layer thickness

The area irradiated with pulse energy density of (20.32 J/cm^2) and pulse duration of 300 μs intermixes to produce an alloy of $Ge_{0.08}Si_{0.92}$ 4.6 μ thick. Alloy layer of

$Ge_{0.06}Si_{0.94}$ 6.5 μ thick is created when the area is treated with higher pulse energy density. Figure 4 shows the top view of such a laser treated region.

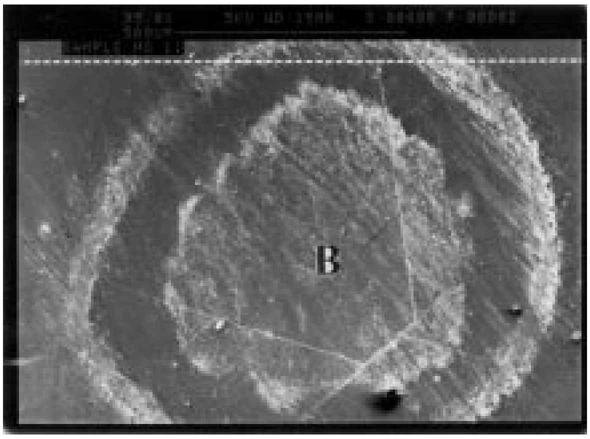
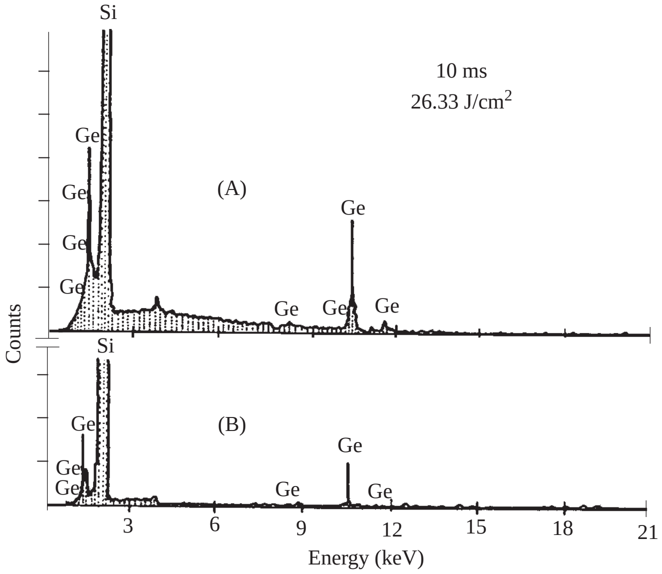


Figure 4. SEM micrograph of sample 1250 Å Ge/Si irradiated with 20.32 J/cm^2 of 300 μs pulse duration

The EDS spectra for samples 1250 Å Ge/Si(111) irradiated under different laser conditions are presented in Figure 5.



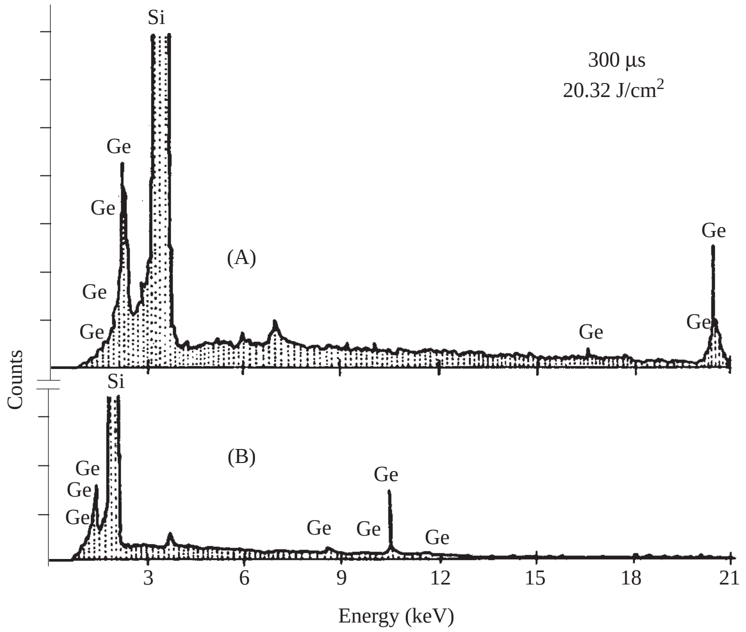


Figure 5. EDS spectra from laser processing 1250 Å Ge/Si sample at regions (A) and (B) shown in Figures (2) and (4).

The aspect of the irradiated zone as observed by SEM depends on laser energy density as follows:

1. The irradiated zone having been exposed at energy density <26.33 J/cm^2 differed from the unirradiated surface only by the appearance of sharp crack lines which form definite angles of 60° among themselves (see Figure 6). The mechanism of crack formation is due to thermal shock (high cooling rate) which in turn places compressional stresses on the germanium layer [9].

2. At higher energy density a protuberence is produced as shown in Figure 7. The formation of such a structure can be explained as follows: when the laser beam has sufficient energy melting zones are produced. The outer zone in contact with bulk material cools rapidly through thermal conduction, while the central zone cools through radiation. In such cases, the solidification process begins from the outer zone towards the center, i.e the inner part which is in liquid phase will exert a pressure on the solidified surface layer and then produces as a result of breaking the weak part of the surface layer [10]. Further SEM work is in progress.

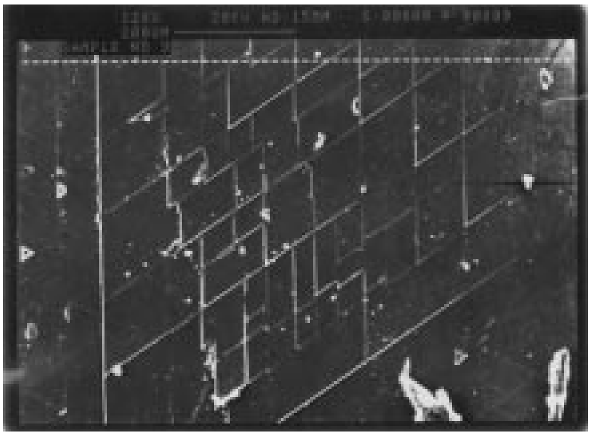


Figure 6. SEM micrograph showing crack lines.

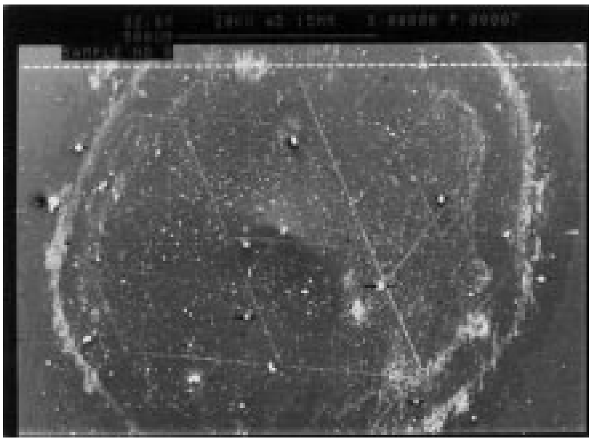


Figure 7. SEM micrograph of laser processed region irradiated with 29.9 J/cm^2 of 10 ms pulse duration showing the central protuberence

4. Conclusions

Summarizing the results we can draw the following conclusions:

1. Epitaxial Ge-Si heterojunctions can be formed by pulsed laser processing of Ge thin films deposited on Si substrate over a certain range of energy density and pulse duration.
2. The composition and thickness of Ge-Si layer strongly depends on laser fluence and pulse duration.
3. Ge concentration has maximum value at the vicinty of the surface and then decreases

sharply as depth increses.

4. The meachanism for crack lines is thermal shock in nature.
5. A central protuberence appeared when the Ge surface is exposed to high energy density.

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