THE INFLUENCE OF THE ERBIUM ATOM ON THE OPTICAL PROPERTIES OF EPITASIAL SILICON FILMS

Bazarbaeva H.
Kudainazarov A.
Saburov N.
Sharibaev M.
Karakalpak state univesity named after Berdakh.

https://doi.org/10.5281/zenodo.14491942

Abstrct. *The results of growing erbium-doped epitaxial silicon layers using two different growth modes: conventional molecular beam epitaxy (MBE) and solid-phase epitaxy (SPE) are presented. It has been shown that an erbium-doped silicon layer, when deposited by SPE onto a cold substrate and subsequent annealing, exhibits more intense photoluminescence at a wavelength of 1.54 μm than layers grown by MBE.*

Key words: *photoluminescence, epitaxial film, deformation, intensity, mechanical stress.*

ВЛИЯНИЕ АТОМА ЭРБИЯ НА ОПТИЧЕСКИЕ СВОЙСТВА ЭПИТАЗИАЛЬНЫХ КРЕМНИЕВЫХ ПЛЕНОК

Аннотация. *Представлены результаты выращивания эпитаксиальных слоев кремния, легированных эрбием, с использованием двух различных режимов роста: традиционной молекулярно-лучевой эпитаксии (МЛЭ) и твердофазной эпитаксии (ТФЭ).*

Показано, что слой кремния, легированный эрбием, нанесенный методом ТФЭ на холодную подложку и подвергнутый последующему отжигу, проявляет более интенсивную фотолюминесценцию на длине волны 1,54 мкм, чем слои, выращенные методом МЛЭ.

Ключевые слова: *фотолюминесценция, эпитаксиальная пленка, деформация, интенсивность, механическое напряжение.*

Introduction. The growing number of studies of erbium-doped silicon is associated with the possibility of using this material to create silicon optoelectronic devices at a wavelength of 1.54 μm [1]. One of the conditions for the successful implementation of silicon device structures is to achieve a high content of optically active centers associated with erbium. When doping silicon with erbium using ion implantation, high-energy ions (0.5–5 MeV) are used.

This leads to the formation of defects that are partially preserved even after prolonged annealing and lead to the precipitation of rare-earth impurities [2]. In ion implantation, as in other doping methods, optically inactive silicide compounds are formed as a result of the interaction of erbium and silicon atoms.

It was found that in order to suppress the formation of erbium precipitates and erbium silicides, it is necessary to carry out the doping process at low temperatures and dope the silicon layers with oxygen to form optically active centers, including Er^{3+} ions [3].

Using the molecular beam epitaxy (MBE) method with the evaporation of silicon and erbium, it is possible to grow layers with a total erbium concentration of up to 10^{22} cm^{-3} [4]. owever, the intensity of photoluminescence in layers with an erbium concentration greater than 10^{18} cm^{-3} begins to weaken, which is probably due to the formation of defects in the crystal structure [4- 6].

Another method that allows growing heavily doped silicon layers is solid-phase epitaxy (SPE). The growth process in it is carried out in two stages: deposition of the layer at low temperatures, when the segregation of the impurity is kinetically suppressed, and subsequent annealing of the amorphous silicon film [6].

The purpose of this work is to study the possibility of growing heavily erbium-doped silicon layers by SPE, exhibiting photoluminescence at a wavelength of 1.54 µm.

Experimental technique

The growth of erbium-doped silicon layers was carried out in an ultra-high-vacuum MBE setup using the device shown in Fig.1 [7]. Si was evaporated from a sublimation source in the form of a rectangular bar heated by passing current, and Er was also evaporated from a sublimation source cut from metal foil.

The substrate was a rectangular silicon plate cut along the (100) or (111) plane from KDB-12 single-crystal silicon. Like the sources, it was heated by passing current.

After annealing the substrate at T=1250°C for 10 min, silicon layers were grown either by MBE at a substrate temperature of 500°C or by SPE on a heated substrate with subsequent annealing min situ.

The PL spectra of the structures were measured at a temperature of 77 K using a BOMEM DA3 Fourier spectrometer with a resolution of 1 cm−1 under pumping by an Ar^{+} laser (with a wavelength of λ=514.5 nm) with a power of 80 mW from the side of the epitaxial layer. The structure of the layers was studied by electron diffraction.

The photoluminescence spectrum of this structure, measured at liquid nitrogen temperature, is shown in Fig. 2. A broad band with a maximum at 6500 cm^{-1} is characteristic of the PL of the Er^{3+} ion in Si:Er/Si structures obtained by sublimation MBE with a metallic erbium source and containing a higher (compared to the erbium content) concentration of oxygen and carbon.

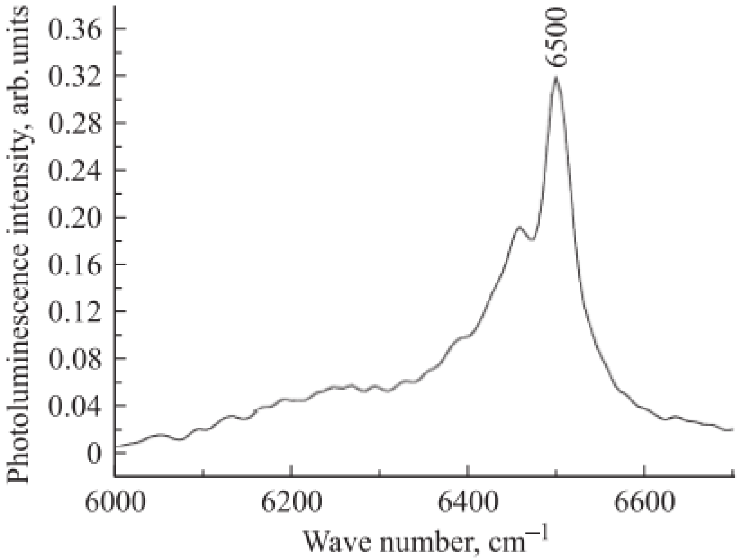

Fig. 1. PL spectrum of the structure grown by MBE. The spectrum was recorded at T=77 K and argon laser pump power P=80 mW.

The photoluminescence spectrum of erbium in an epitaxial silicon layer grown in the SPE mode is shown in Fig. 4. The spectrum contains an intense series of narrow luminescence lines related to the $^4II_{3/2}\rightarrow^4 II_{5/2}$ transition in the 4f shell of the Er^{3+} ion in the known isolated emitting center with cubic symmetry [8]. Such a spectrum is usually characteristic of erbium in single-crystal silicon with a low (compared to the erbium concentration) oxygen content. At the same time, the integrated luminescence intensity of the Er^{3+} ion in the structure obtained in the SPE mode is 2 times higher than that in the structure grown in the MBE process. According to existing ideas about the mechanism of TFE of amorphous silicon layers sawn in a vacuum onto a single-crystal substrate, during annealing the epitaxial crystallization front moves from the single-crystal/amorphous film interface to the surface of the layer [9].

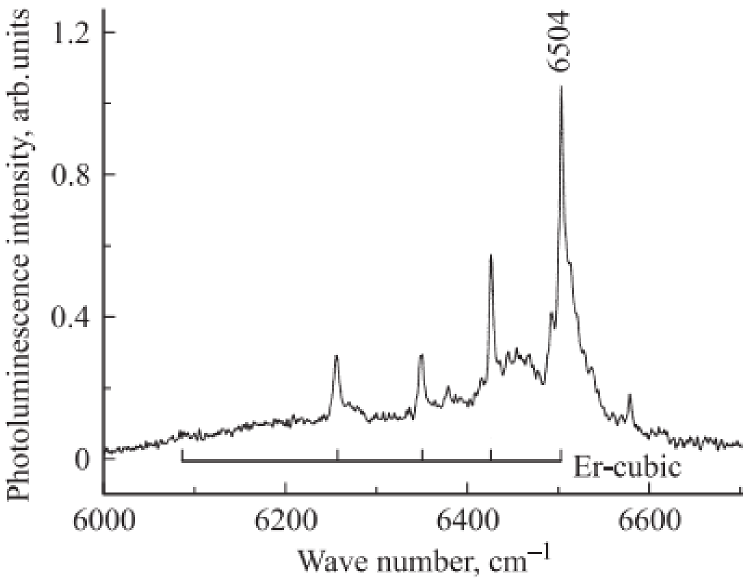

Fig. 2. PL spectrum of the structure grown in the SPE mode. The PL recording conditions are the same as for the spectrum in Fig. 1.

If at an annealing temperature of 600˚C the crystallization of amorphous silicon on a single-crystal substrate occurs due to the epitaxial ordering of atoms of the amorphous phase near the single-crystal/amorphous film interface, then at 800˚ C there is additional nucleation and growth of randomly oriented crystallites in the bulk of amorphous silicon. The epitaxial crystallization rate at 80˚ C is 2.2–10 nm/min. Such a high crystallization rate leads to the fact that at the end of annealing part of the surface is occupied by the single-crystal phase, and the other part is occupied by the polycrystalline phase. The effect of oxygen on the slowing down of the crystallization rate was reported in [10]. However, when oxygen was admitted in our experiments at the moments of suspension of the growth process, an insignificantly thick layer of adsorbed gas is probably formed, which, perhaps, is only partially captured by the growing layer. As a result, the total amount of oxygen introduced into the layer is insignificant. This apparently causes the observed changes in the photoluminescence spectrum of Er^{3+} ions in silicon layers grown by the SPE method. Thus, the solid-phase epitaxy method allows one to form a heavily erbium-doped layer in a silicon film sawn in an ultrahigh vacuum, from which more intense photoluminescence is observed than from a layer grown by the molecular beam epitaxy method.

REFERENCES

1. N.A. Sobolev. FTP29, 1153 (1995).
2. A. Polman. J. Appl. Phys. 82, 1 (1997).
3. Y. Ho Xie, E. A. Fitzgerald, Y.J. Mii. J. Appl. Phys.70, 1153 (1991).
4. H. Efeoglu, J.H. Evans, T.E. Jackmann et al. Semicond. Sci. Technol.8, 236 (1993).
5. R. Serna, M. Lohmeier et al. Appl. Phys. Lett.66, 1385 (1995).
6. V.G. Zavodiskii, A.V. Zotov. Phys. Stat. Sol.(a). 72, 391 (1982).
7. S.P. Svetlov, V.Yu. Chalkov, V.G. Shengurov. PTE4, 141 (2000).
8. H. Przybylinska et al. Phys. Rev. B54, 2532 (1996).
9. I.G. Kaverina, V.V. Korobtsov, V.G. Lifshits. Thin Sold Films 177, 101 (1984).
10. C.W. Nogee, J.C. Bean, C. Foti, J.M. Poate. Thin Sold Films 81.1(1981).