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半絶緣 갈륨비소의 赤外線 映像에 의한 웨이퍼成長條件 및 溫度從屬 퀀칭율 證明

(Evidence of Material-dependent and Temperature-dependent Quenching Rates by Infrared Imaging in S.I. GaAs)

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요 약

적외선 영상기법을 이용해 반절연 GaAs 기판 내의 EL2 영상에 대한 Photoquenching의 영향을 성장 원상태(as-grown)의 샘플과 열처리 샘플을 중심으로 분석하였다. 본 논문에서 Quenching 메커니즘은 샘플에 의존적이고 또한 Quenching율은 샘플의 성장조건과 Quenching 온도에 따라 다르다는 것을 영상적으로 정확히 증명하고 있는데 이는 기존의 연구내용과는 다소 상충된 새로운 내용이다.

Abstract

The effect of photoquenching on infrared images of the EL2 center in semi-insulating(S.I.) GaAs has been studied using near infrared transmission techniques. Particular interest is devoted to as-grown and annealed samples of undoped S.I. GaAs. It is found that the quenching mechanism is different in each sample and also the quenching rate is dependent on the materials and the quenching temperature which is somewhat inconsistent with other existing publications.

Keyword : S.I. GaAs, EL2, Photoquenching, Quenching rate, Infrared imaging

I. Introduction

Undoped semi-insulating GaAs(S.I. GaAs) grown by the Liquid-Encapsulated Czochralski(LEC) technique is of great importance at the present time as a substrate material for integrated circuit fabrication. This material contains a midgap donor level, EL2, which is believed to cause the semi-insulating behavior by compensating the shallow impurities. A major objective of most of the work reported to date has been to discover the identity of this defect. Despite a number of papers which have been devoted to this subject, no general consensus has yet been reached on the identification of EL2. Lately, however, there is growing evidence

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that EL2 is probably a complex involving AsGa and one or more other intrinsic defects, and also that there is a family of EL2 defects rather than only one.

Perhaps the most discussed and intriguing property of EL2 is its photoquenching behavior, which has been observed in photocapacitance[1], photoluminescence[2], photoconductivity[3] and infrared absorption[4]. It is well known that S. I. GaAs exhibits an absorption band in the 1.0-1.3 eV range which has been attributed to the EL2 defect. This absorption is believed to be due to an intracenter transition between the EL2 ground state(EL2°) at midgap and an excited state. It can be completely quenched by irradiating the material with photons of about 1.1-1.2 eV energy.

This photoquenching effect occurs when the defect is transformed from its normal state(EL2°) to a metastable state EL2*[1]. The normal state can be recovered by heating the sample above a critical temperature Tth. This threshold usually takes place at some 110-130°K.

Ⅱ. Infrared Imaging

As mentioned in the introduction, S.I. GaAs has an infrared absorption band due to the EL2 defect. On the basis of this property, infrared transmission images of defects can be obtained on GaAs samples, especially LEC grown S.I. materials. Therefore those images are directly related to the characteristic defects; if there are some fluctuation in the defects, this immediately affects the infrared absorption images.

Brozel et al.[5] initially found that the infrared transmission(IRT) images disappear after photoquenching (at T=12 °K) but later Castagne[6] also showed that above T=80 °K only the background of the IRT image was affected by photoquenching(PQ) whereas the cell pattern and relative contrast was kept unchanged[7, 8].

This IRT imaging technique is useful for the evaluation of semi-insulating GaAs wafers because it is simple and nondestructive as a routine test procedure[9].

Ⅲ. Experimental

The experimental set-up has been previously described[10] ; it consists of a cryogenic cell containing the GaAs wafer and is provided with glass windows. The circulating liquid nitorgen or liquid helium allows the sample to be cooled down to 80 °K or 10 °K ; it was carefully verified that no significant temperature deviation exitsted between the sample and the coolant. This temperature is satisfactorily far from the threshold T_{th}.

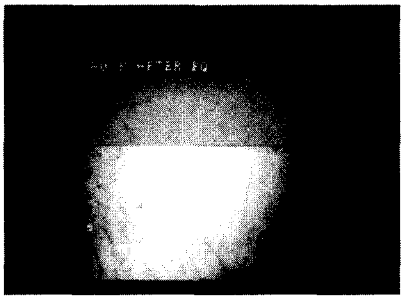
A low power lamp and scattering screen give an extended uniform light source and the observation is made through the sample by a vidicon TV camera and a digital image processing system.

Photoquenching was carried out using tungsten halogen bulb to provide white light illumination of the sample ; several durations and intensities were tested in order to reach a saturated PQ effect. The samples are from as-grown (COMINCO) and annealed (WACKER) of undoped SI materials. The high contrast enhancement properties of the image processing system allows routine experiments to be made on thin samples(300㎛).

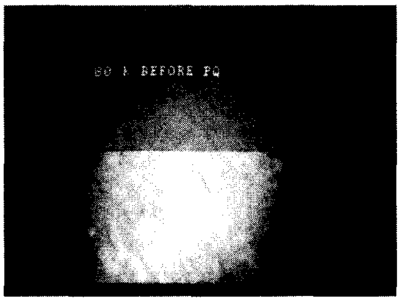
Ⅳ. Results and Discussion

Complete results of PQ at 80 °K and 10 °K are shown in Figure 1 and Figure 2. Adapted image processing facilities also allows to improve the contrast resolution as shown in the boxes in the figures. By the comparison of a) in Figure 1 and a) Figure 2 the annealed sample is much more homogeneous than that of the as grown sample. These results are well consistent with the annealing mechanism; many publications have been reported that annealed samples are more homogeneous than as grown samples in defect distributions(EL2 distributions)[5-7].

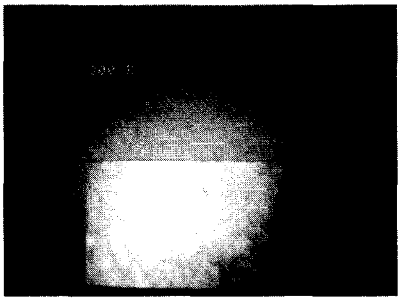
The photoquenching is carried out for 30 min duration with 30 W illumination power. It is found that 30 min duration of PQ at T=80K is not sufficient to give a complete quenching effect. This is confirmed by observing the image of e) in Figure 1. This image is certainly more blurred or homogeneous than that of b) in Figure 1. But there still remains some structure, which means that it is not fully quenched. We verified, however, that if we carry out 60 min quenching under the same conditions, this image becomes totally saturated. This is interpreted as being due to the quenching effect being dependent on the quenching duration at a particular temperature. On the other hand, at T=10 °K, the image is completely quenched as shown in e) of Figure 1. This is another mechanism that the quenching efficiency is also related to the quenching temperature.



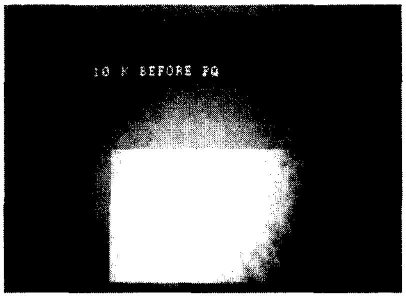
(a)



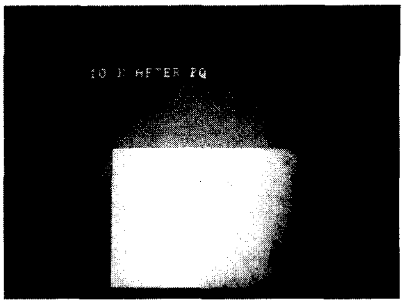
(b)



(c)



(d)



(e)

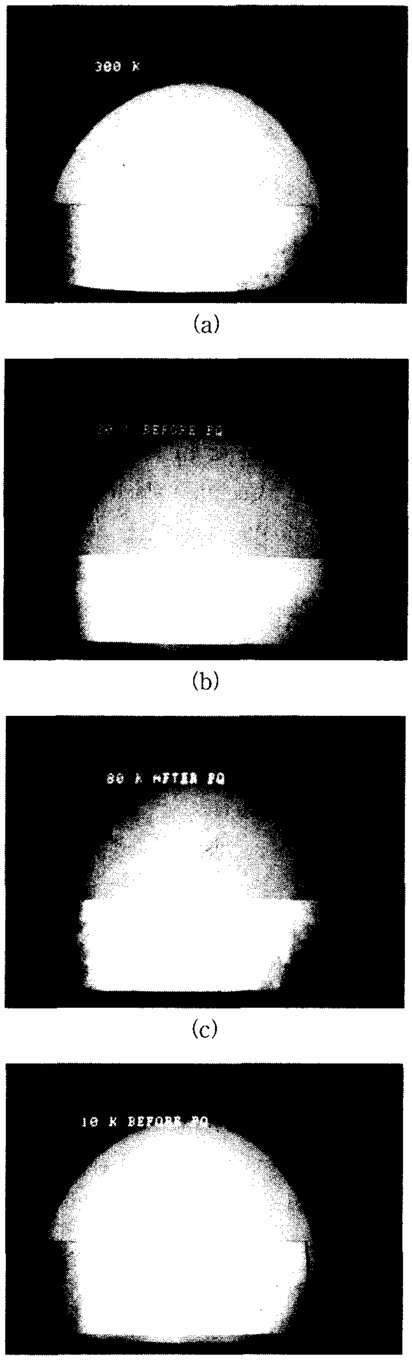
그림 1. As-grown LEC GaAs 재료(COMINCO)에 대한 IRT 영상 (a) 상온, (b) T = 80 °K PQ전, (c) T= 80 °K, PQ후, (d) T = 10 °K PQ전, (e) T= 10 °K PQ후

Fig. 1. IRT images of an as-grown undoped LEC GaAs material (COMINCO) at room temperature (a), at T = 80 °K before PQ (b) and after PQ (c), at T = 10 °K before PQ (d) and after PQ (e).

The curious and somewhat astonishing results are in Figure 2 As shown in c) of Figure 2, a high contrast image appears after PQ at T=80K in the annealed material. But after having quenched at T=10 °K, the image is bleached like the normal quenching behavior such as in e) of Figure 2. Moreover the structure of c) in Figure 2 was little affected by the quenching duration which is different to the result in c) of Figure 1.

The structural appearance, perhaps in this publication being reported for the first time, in c) of Figure 2 could be explained in that EL2 has a complex structure which consists of elements having different quenching rates depending on the temperature.

Therefore, the homogeneity of image b) in Figure 2 means that the distribution of EL2 is almost the same across the sample and the inhomogeneity of c) in Figure 2 could be explained as the different EL2 element distributions. The image e) in Figure 2 in conjunction with the image e) in Figure 1 is considered as being completely quenched at such a low temperature. In other words, all of the EL2 elements are transfered to the EL2 metastable state(EL2*) at very low temperatures. These images in Figure 2 also provide a good indication of a temperature-dependent quenching rate that is consistent with other publications, for example J. P. Fillard et al.[11].

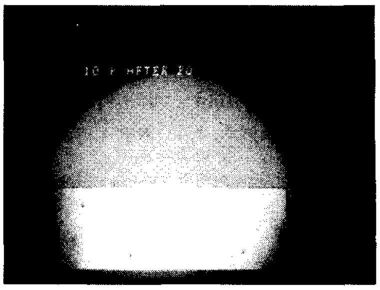


(a)

(b)

(c)

(d)



(e)

그림 2. 열처리한 LEC GaAs 재료(WACKER)에 대한 IRT 영상 (a) 상온, (b) T = 80 °K PQ 전, (c) T= 80 °K PQ 후, (d) T = 10 °K PQ 전, (e) T = 10 °K PQ 후

Fig. 2. IRT images of an annealed undoped LEC GaAs material (WACKER) at room temperature (a), at T = 80 °K before PQ (b) and after PQ (c), at T = 80 °K before PQ (d) and after PQ (e).

Ⅴ. Conclusion

From these experiments it has been convincingly shown that the quenching mechanism is material-dependent and temperature-dependent. In consequence, it is recommended that experiments need to be made at temperature much lower than Tth (110-130 °K) in order to study the EL2* structure. One model has been proposed for the identification of EL2 defect on the basis of infra red imaging. Further studies are needed to justify the proposed EL2 model along the different PQ conditions.

High contrast images are obtained for annealed sample after PQ at T=80 °K which reflect the different EL2 components and these images are little affected by the PQ duration. This is in contrast to the as-grown material images which become completely bleached after a longer period of PQ.

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