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Theoretical and practical research of the use of inductors for improving DLTS characterization of semiconductors

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Abstract

In 1982 Broniatowski [J. Appl. Phys. 56 (1982) 2907] estimated theoretically what is the change of capacitance as seen by a capacitance meter if an inductor is set in series with a DLTS sample. To the best of our knowledge, there have been no experimental studies on the inductor coupled in series with the sample to clarify in which way the inductor would actually change the DLTS spectra.

In this paper, we study for the first time theoretically and experimentally, the effects of an inductor on the capacitance of a sample, as seen by the capacitance meter. We also determine the resonance condition that increases the measured signal and we also study the separation of the signal peaks, proposing a novel way to obtain the activation energy (E_a), the capture cross-section (σ), and the density (N) of deep levels.

Finally, we show our preliminary results using light in connection with the inductor in DLTS to improve the accuracy of the measurements.

As an illustrative example, we have investigated the DLTS of $Al_xGa_{1-x}As$, with Al molar compositions of $x = 0.22$, 0.3, 0.4, 0.6 and 0.92. Both doped and un-doped samples are studied. AlGaAs is known to exhibit at least four DX centres [J. Appl. Phys. 67 (1990) R1; Semicond. Semimetals 38 (1993) 235; International Symposium, Mauterndorf, Austria, 1991; J. Electron. Mater. 20 (1991) 1], the properties of which depend on x, but they are found to overlap with each other, which makes it hard to determine their properties precisely. We show by computation that, adding the inductor to the sample improves the resolution of the DLTS measurement, separates the peaks and facilitates determining accurate values of E_a, σ, and N. Finally, the use of light was found to maintain the DX centres de-ionized, thus keeping the capacitance at reverse bias rather constant which, in turn, enabled us to easily achieve exact resonance conditions for the best effect.

Keywords: DLTs; AlGaAs; Deep level

1. Introduction

DLTS is a powerful technique which enables to get a wide electrical characterization of deep levels in semiconductors [2]. Unfortunately in some semiconductors, the peaks are very close, so they overlap each other, which impedes the accurate determination of fundamental parameters of the deep levels as are concentration, capture cross-section and activation energy [3]. One of this semiconductor is AlGaAs, which in spite of having been studied intensively, its four deep levels overlap depending on the concentration of composition of Al, making inaccurate determination of the deep levels parameters.

On the other hand in 1982, Broniatowski [1] studied the relation of high resistance in series with DLTS Schottky samples, and proposed what would be the behavior for inductances in series. We have performed intensive research, and to our knowledge, we have not found any further work on the topic, neither theoretical nor experimental.

Our work is a theoretical and experimental research on the use of inductance in order to separate peaks, and its application to AlGaAs to get more accurate parameters for its deep levels.

2. Theoretical analysis

A capacitance meter in a DLTS scan assumes that the capacitance C_p we are measuring is in parallel with a resistance R_p as it is shown in Fig. 1.

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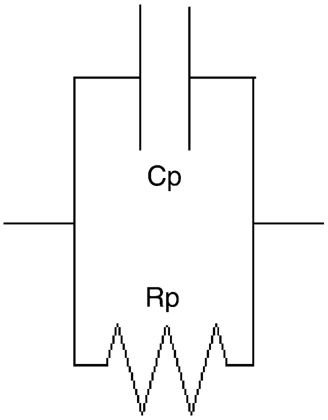

Fig. 1. Capacitance and resistance in parallel as seen by a capacitance meter.

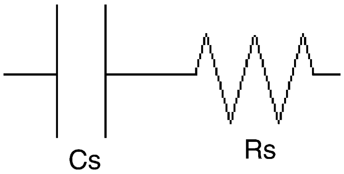

Fig. 2. Capacitance and resistance in series as in a Schottky contact.

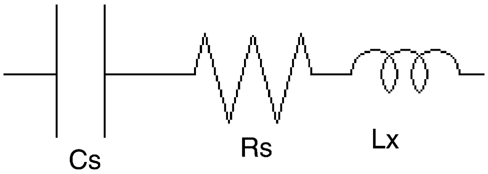

Fig. 3. Inductance L_x added in series to a Schottky model of capacitance and resistance in series.

While the real situation is a capacitance C_s and a resistance R_s in series as shown in Fig. 2.

In order to get the equivalence of the circuits, one has to compare the complex impedances of both of them. Both circuits are equivalent in case $R_s = 0$ or $R_p \to \infty$.

If one adds an inductor L_x in series with the sample, as shown in Fig. 3, one arrives for the following complex impedances equations.

For the total impedance of the series of the sample's resistance R_s, the capacitance's sample C_s and the inductor L_x

$$Z_T^s = \frac{jwR_sC_s - w^2L_xC_s + 1}{jwC_s} \tag{1}$$

And for the parallel arrangement of resistance R_p and capacitance C_p

$$Z_T^p = \frac{R_p}{1 + jwC_pR_p} \tag{2}$$

Where j is the imaginary unit and w is the frequency at which the capacitance meter is measuring.

As these two expressions should be similar, one arrives at the following expression relating the change in capacitance C_p as a function of change in capacitance C_s in a first approximation

$$\frac{\partial C_p}{\partial C_s} = \frac{A^2 - (1 - w^2L_xC_s)^2}{(A^2 + (1 - w^2L_xC_s)^2)^2} \tag{3}$$

Where $A = wR_sC_s$ is the quality factor.

Here one finds a typical resonance condition, that is to say, in case one chooses the appropriate value for L_x, one can achieve

$$1 - w^2L_xC_s = 0 \tag{4}$$

In this case, Eq. (3) becomes

$$\frac{\partial C_p}{\partial C_s} = \frac{1}{A^2} \tag{5}$$

This analysis is a motivation to make the experimental study of use of inductors in DLTS. To our knowledge, nobody has done this before, so we have engaged in this research. In

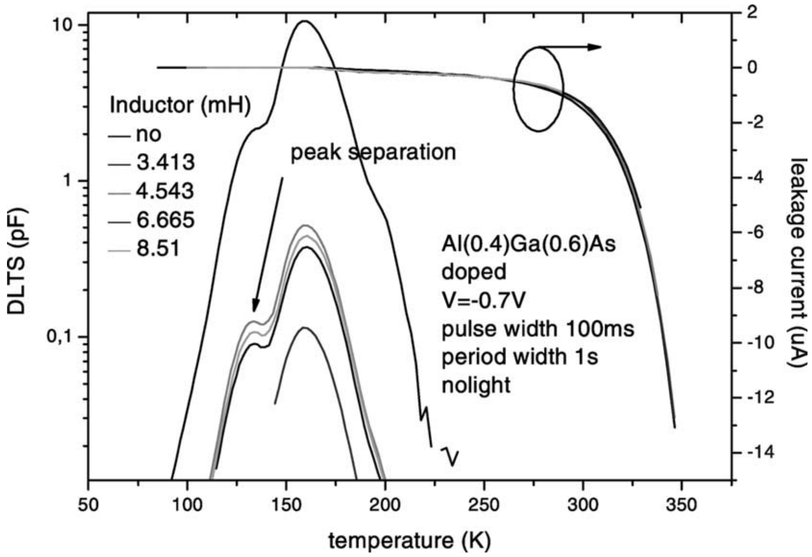

Fig. 4. DLTS spectra with no light.

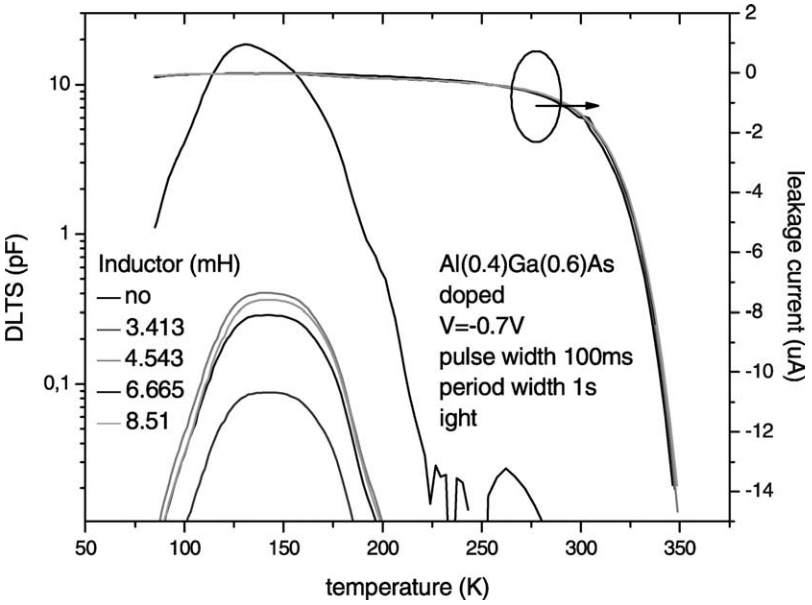

Fig. 5. DLTS spectra with light.

order to get reliable results, we have chosen AlGaAs because it is the material which has been widely studied, so its deep levels are well known.

3. Experimental analysis

We have studied several Al(x)Ga($1-x$)As samples with $x = 0.22$, 0.3, 0.4, 0.6 and 0.92 grown by MBE. The samples were grown on n-GaAs substrate, 2 μm thick, doped with Si. A cap layer of 10 nm GaAs was added to avoid oxidation.

As can be seen from Fig. 4, Al(0.4)Ga(0.6)As has an overlapped peak which appears as a shoulder around 135 K. Due to its presence, it is possible to ascertain that there is a deep level around this temperature, but due to the overlapping it has not been possible to calculate it exactly.

The use of inductors helps to separate these two peaks; as can be seen from Fig. 4, allowing a more accurate measure of the properties of this level. This calculation is in progress.

It is important to note that the peaks reduce in intensity when using the inductors, which is in contradiction with the theory. Our preliminary analysis suggest two possible reasons:

(1) a drastic drop in the voltage in the diode due to a high drop in the inductance;
(2) a compensation effect done by the electronics on the DLTS device.

In Fig. 5 it is shown how the presence of light increases the deep level around 135 K, taking it to a same magnitude as the one around 165 K.

4. Conclusion

We have proved experimentally the use of inductors in series with a DLTS sample in order to separate peaks. Research is still necessary to understand the decrease in the peak intensity in contradiction to theory and the introduction of the effect in calculating deep levels parameters.

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