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## ANNEALING OF HIGH DOSE IMPLANTED GaAs WITH HALOGEN LAMPS

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**Résumé** - Le recuit de GaAs implanté par un système de deux lampes à halogène est présenté. Le confinement de l'échantillon monté entre une plaque de silicium et une plaque de quartz permet d'obtenir une protection par contact. Cette configuration a permis l'étude par diffusion Raman de la reconstruction du réseau cristallin après irradiation ainsi que la limite de dégradation en surface du substrat par perte d'arsenic.

**Abstract** - The use of radiation from two halogene lamps to anneal implanted GaAs has been studied. Contact protection of the substrate is obtained by mounting it in a sandwich configuration between a silicon and a quartz plate. This configuration allows to measure by Raman scattering lattice recovery after irradiation and substrate surface degradation due to arsenic loss.

### INTRODUCTION

The annealing of ion implanted GaAs is the object of a constant research effort to achieve a good control in GaAs devices. Conventional thermal annealing of GaAs often gives unsatisfactory results in both activation of dopants and removal of damage induced by ion implantation. Furthermore, encapsulation of the substrate or a controlled arsenic overpressure are required to prevent the substrate from surface decomposition (As evaporation) at elevated temperatures. This procedure is often delicate and can induce electrical conversion at the surface of a semi-insulating substrate /1/. Therefore GaAs has from the start been a potential candidate for the application of the beam annealing technology. The short and localized heat treatment under beam irradiation was expected to suppress decomposition and thereby improve the properties of the annealed layers. However the results to date on laser annealing of implanted layers in GaAs have not shown substantial improvements as compared to thermal annealing. Major difficulties arising from the fragility and dissociation of the material under laser irradiation are responsible for the limited success achieved in early attempts. More recently the use of lamps to anneal implanted GaAs has brought promising results in electrical activation of dopants /2,3/. Similar results were obtained with a graphite strip heater /4/. The novelty of the technic is a more distributed thermal gradient induced at the surface of the substrate and a longer annealing time (few seconds) as compared to a laser irradiation.

In this presentation the annealing of high dose implanted GaAs with a system of two 150 watts halogene lamps is studied. The optimization of irradiation time has been made for a given induced temperature on the basis of best lattice recovery and minimum surface degradation. The confinement of the sample mounted in a sandwich configuration during irradiation results in the ability of measuring both informations within a single Raman scattering investigation.

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### ANNEALING APPARATUS AND SAMPLE MOUNTING CONFIGURATION

A system of two 150 W halogen lamps as described in ref /5/ was redesigned for the annealing of III-V compounds. The filament of the lamps of this system draws 10A at 15V and has an emission spectrum that corresponds to the blackbody radiation emission at 3400K with a peak at 800 nm. The lamps are mounted in a built in gold coated reflector that focuses the filament 19mm away from the edge of the reflector. The average power density radiated by each lamp at full intensity was measured in /5/ to be  $100\text{W}/\text{cm}^2$ . The annealing set up is schematically drawn in Fig.1. Two lamps facing each other and a silicon sample holder are mounted each on a disk that can be translated on a vertical graduated pole. The lower lamp is strongly defocused with respect to the sample holder and is utilized to prepare it at a constant initial temperature ( $\approx 300^\circ\text{C}$ ). This procedure is necessary to reduce the thermal stress in the semiconductor when the elevated annealing temperature is suddenly induced. The upper lamp is then lighted to ramp the sample to its final temperature (800 to  $1100^\circ\text{C}$ ). The temperature induced on the irradiated sample was carefully measured with a thermocouple in mechanical contact with the sample holder. The spatial temperature profile indicates that the temperature is relatively uniform across the studied samples ( $4\times 4\text{mm}$ ). The temporal temperature profile is shown in Fig.2. It indicates that the final temperature induced by the lamps due to the experimental choice of the upper lamp position is  $1000^\circ\text{C}$  and that 8 secondes of transient regime are necessary to reach thermal equilibrium.

The GaAs substrate need to be protected from sudden surface decomposition at this temperature. A closed contact configuration was chosen for protection with the sample sandwiched between the silicon sample holder and a quartz plate. The GaAs sample is placed upside down on a floating silicon wafer so that the two polished surfaces are in contact. As shown in the inset of Fig.1. A heavy quartz plate covers the structure and press it tight. Similar sandwiched configuration has been used successfully to protect II-VI compounds during an annealing cycle /6/. Finally as an extra protection the whole system is kept in a clean nitrogen environment.

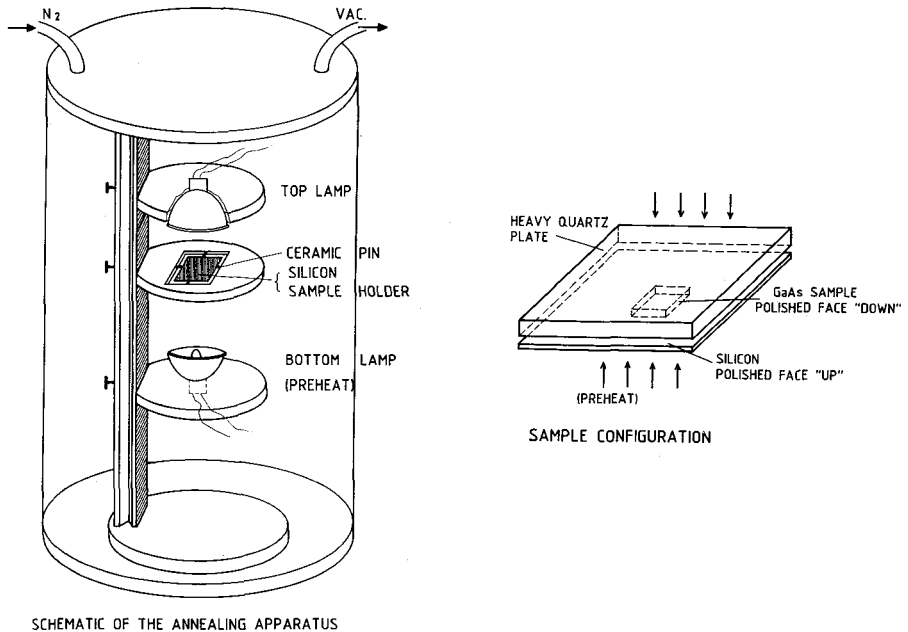


Fig.1 : Schematic of the annealing apparatus and sample mounting configuration.

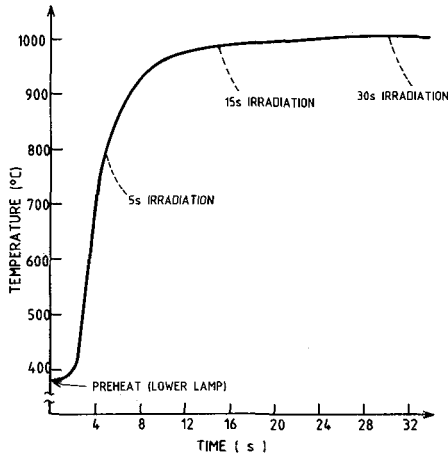


Fig.2 : Temporal temperature profile induced on a sample by the halogen lamp system.

## EXPERIMENTAL RESULTS

The lattice reconstruction under irradiation of heavily damaged GaAs layers has been studied. Chromium doped (100) GaAs substrates were implanted with  $\text{Te}^+$  ions ( $1 \times 10^{15}/\text{cm}^2$ ) at 250 keV resulting in a 1000 Å amorphous layer. Both single crystal and implanted samples were ramped to 1000°C in the lamp system described above for a total time (including rising time) varying between 5 and 60 sec. This is illustrated in Fig.2.

The first experiments were carried out on crystalline GaAs to check the degradation induced by irradiation. Raman scattering investigation showed the formation of crystalline arsenic traces at the surface of the sample for total irradiation time above 30 seconds. Crystalline arsenic belongs to the point group  $\bar{3}m$  and there are two atoms in the unit rhombohedral cell. There are three optical modes which are Raman active : the single mode  $A_{1g}$  (LO) and the doubly degenerate  $E_g$  (TO) modes. A clear increase in the As peaks could be measured with increasing exposure time. The presence of traces of crystalline As can be attributed either to an evaporation and recrystallization of As at the surface of the wafer due to the confinement of the pressed sandwiched configuration of the sample, or to a thermal oxidation with As retained in the interfacial region during growth. This last possibility has been reported in ref./7/.

The LO and TO modes of crystalline GaAs (292 and 267  $\text{cm}^{-1}$  respectively) are sufficiently separated from the LO and TO modes of crystalline arsenic (257 and 199  $\text{cm}^{-1}$  respectively) to allow ready identification of the separated species. It is then possible to carry the experiments on the amorphized substrate and follow simultaneously the lattice reconstruction and the surface decomposition. The Raman scattering measurements were made with the probing laser beam at Brewster incidence to minimize unwanted scattering from surface irregularities. The scattering geometry was  $Z(X+Y, X+Y)Z$  in order to detect the LO peak of crystalline GaAs (the only GaAs Raman active peak allowed in this configuration). The increase of the LO (292  $\text{cm}^{-1}$ ) peak is clearly an indication of lattice reconstruction since this peak is completely inexistant in the starting amorphous material.

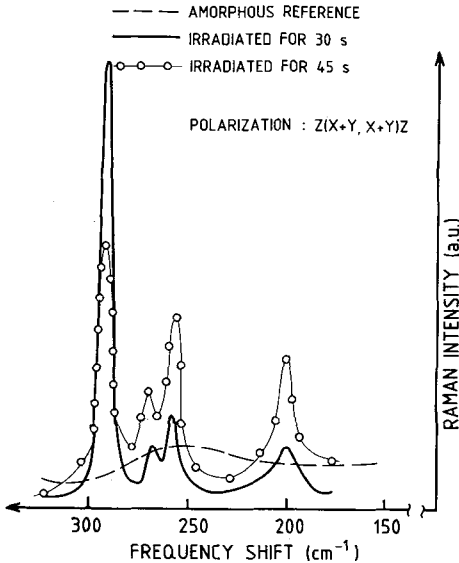


Fig.3 : Raman scattering spectra of samples "over irradiated". The As peaks are the two low frequency peaks (199 and 257  $\text{cm}^{-1}$ ).

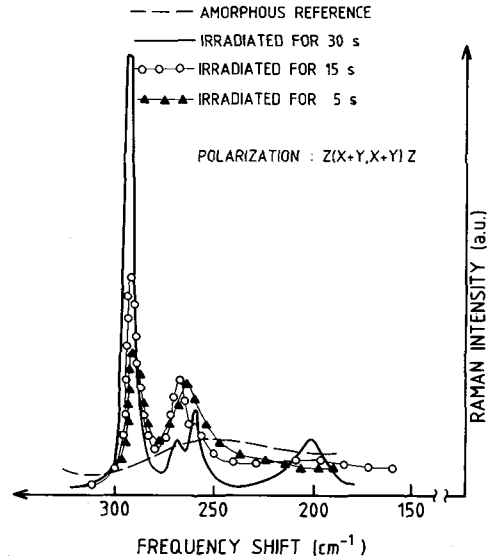


Fig. 4 : Raman scattering spectra of samples "under irradiated". The GaAs peaks are the two high frequency peaks (267 and 292  $\text{cm}^{-1}$ ).

When the sample is irradiated for times longer than 30 seconds the resulting spectra are shown in Fig.3. The As peak intensities are increasing with annealing time and the GaAs peaks are present. A well defined LO peak and a small TO peak attributed to residual disorder appear. It can be concluded that annealing times over 30 seconds result in recrystallization of the amorphous layer but induce a too important surface decomposition. When the exposure time is reduced below 30 seconds the resulting Raman spectra are shown in Fig.4. It can be seen that no crystalline As (or only a very small amount) can be detected and that the highest GaAs LO peak is obtained for 30 seconds exposure time. When this time is reduced below 15 seconds, the spectrum shows the evidence of a resulting GaAs disorder state [8] intermediate between amorphous and crystalline phases. The optimum (highest LO for GaAs and lowest As peaks) total annealing time for an induced temperature of 1000°C is then around 30 seconds. In this case the intensity of the GaAs LO peak is 60 % of a single crystal reference with comparable position and profile.

As a conclusion it has been shown that heavily damaged by ion implantation GaAs layers could be reconstructed with a halogen lamp anneal and that Raman scattering is an elegant method to follow simultaneously this reconstruction and the surface degradation. Further work to fully characterise the annealed crystal structure and to measure electrical activation is on the way and will be reported latter.

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