Qatar Univ. Sci. J. (1995), 15 (2) : 301 - 306

ANALYSIS OF DOPANT DIFFUSION IN MOLTEN GERMANIUM INDUCED BY PULSED ND : YAG LASER

BY

ALI M. MOUSA AND RAID A. ISMAIL

School of applied science University of Technology Baghdad - IRAQ

دراسة تحليلية للانتشار المحتث للشوائب في الجرمانيوم بوساطة ليزر النديميوم - ياج

علـــي مطشـــر موســـى ، رائـد عـبد الوهـاب اسـمـاعيل

درست عملية الانتشـار المحتث بوسطة ليزر النـديميوم ياك النبضي بطول موجـي ١,٠٦٤ مايكرومتر وبزمن نبضـه ٣٠٠ مايكرو ثـانية لعناصر مختلفة ضمن الجرمـانيوم النقي وذلك بغمر الجرمـانيوم في محاليل الشوائب للحصول على طبقة مشابـه من الجرمانيوم . استخدمنا طريقة المجسـات الاربعة لقياس توصيلية الطبقة المشـابه ولـدراسة تـأثير المعلمات الاساسية مثـل كثافـة الطاقة ، محلـول الشائبـة وظروف التلـدين . العينات المشابـه اخضعت لعمليات تلدين حـرارية تقليدية)٢٠٠ - ٥٠٠م ولزمـن ٤٥ دقيقة) ولعمليات تلـدين بواسطـة الليزر النبضي (لكثـافات طـاقة ٢,٥ - ٩,٦ جـول / سم٢) بهدف الوقـوف على أفضل ظروف تلدين .

من القياسات تبين لنا حصول تناقض مضطرد في المقاومة الكهربـائية السطحية بزيادة كثافة طاقة الليزر ولكل القيم الاكبر من ١٠ جـول / سم^{٢} . كذلك ظهر لنا ان توصيلية الطبقـة المشابه تزداد بوجود المجال الكهربـائي الخارجي ودرجة حرارة القـاعدة . وان درجة الفعـالية الكهربـائية للشوائب كـانت افضل عند التلدين بواسطة الليزر (تحت الظروف المثلى) بالمقارنة مع التلدين الحراري التقليدي .

Key Words : Dopant diffusion, germanium, Pulsed ND : YAG LASER

ABSTRACT

Laser - induced diffusion of various dopant elements into intransic germanium based on the dipping of Ge into dopant solution, have been used to produce doped ge layer using yag pulse laser with 300us duration ($\lambda = 1.664\mu$ m), Four point probe measurments of the layer conductance were used to study the effect of the doping controlled parameters mainly laser fluence, dopant solution, and annealing conditions. Doped sample T_{ann} = 200- 500 C for time t_{ann} = 45 subjected to subsequent thermal annealing (at the temperature and to plused leacr annealing (energy density in a min) pluse E=5.2 - 9.5 J/cm^2) in order to establish optimal condition.

A monotonic decrease in the sheet resostance with increasing energy density for all values of E > 10 J/cm^2. The layer conductance of doped layer increased with the values of electric fleid and substrate temperature. Thr degree of electric activation of laser annealed (under opitmal conditions) doped layer was much better than the corresponding parmeters of the layer annealed thermally under any condition in our experiments.

INTRODUCTION

Laser - induced doping is one of the important methods for making solid state devices. The diffuculty with such an approach will increase with the increase in the number of steps. There is an intensive effort to develop this technique by a number of groups [1-3]. Single step laser - induced diffusion of silicon has been achieved by a number of groups, using the simultanous laser generation of dopant species and rapid surface heating to promote diffusion into the substrate [4 - 7] The goal is optimization of device performance, which is intimately coupled to the irradiation parameters and dopant species it should be pointed out that out of thirty papers have been published on the subject so far deal with one or two dopant species.

In this paper we present "for the first time" our studies on the dependence of the electrical properties of Ge doped in this way on the parameters of laser radiation.

Our investigation had two aims : firstly to investigate the feasibility oof incorporation of impurities into Ge by single step laser - induced diffusion, secondly to find the effect of irradiation paramcters on the electrical properties.

EXPERIMENTAL TECHNIQUE

The starting material in our studies was (311) oriented 45Ω - cm germanium sample, 500 μm thickess. The surface preparation consisted of mechanical polishing with (Al_2O_3) powder of decreasing grain size (5,3,1, and 0.5 μm) on microal oth until a mirror - smooth surface evolved. For each step, Ge dipped into solution containing one of the following dopants (Al, Zn, Ni, B, Cd). The experimental arrangment arrangment used is shown in Fig. (1).

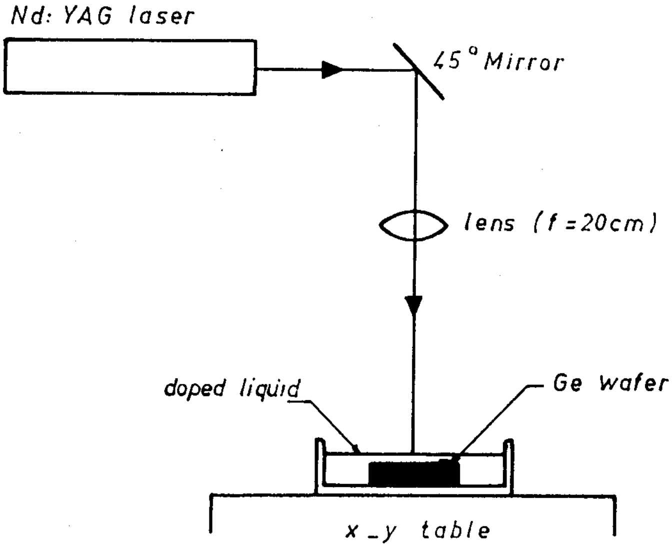

Fig. (1) Schematic Drawing of Experimental Set - Up.

Irradiations are performed by single laser pulse (Wavelength 1.064 μm of TEMoo mode, pulse duration 300μS) in the sample between (9.51 -15.2 J/cm2) at room and different temperatures. By making successive overlapping laser spots with overiapping ratio 18% as shown in Fig. (2).

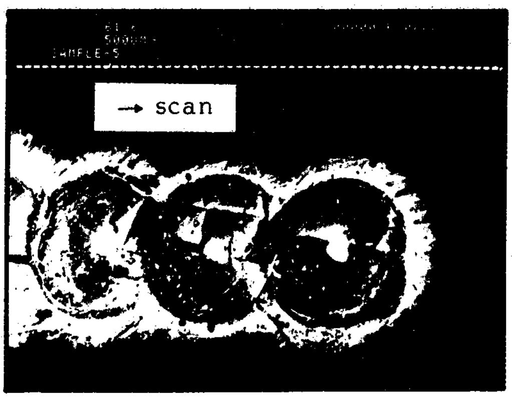

Fig. (2) Sem Micrograph of overlapping laser spots.

The thickness of the liquid dopant layer convening the Ge sample was (1mm) typically, and the spectral transmission of dopant solution were taken into consideration as shown in table (1).

The following heat - treatment has been applied.

(I) furnace annealling in evacuated quartz ampoule at different temperatures (for tann = 45min.) followed by slow cooling.

(2) Single laser pulse of energy densities (5.2 - 9.51 J / cm^2). Futhermore. the doping of some samples were accompanied by electric field it. The changes in the properties of the surface as a result of the interaction with pulsed laser at different conditions was investigated by measuring the sheet resistance using four point probe (FPP 5000).

RESULTS

The results of our investigation of the dependence of the electrical properties of the irradiated germanium layers on the irradiated conditions are presented in Figs. (3-9), and they can be summarized as follows :

Figure (3) shows the sheet resistance of the five different impurties versus the laser enegry density at the substrate. The curves are quite similar, and the sheet resistance decreases with increasing energy density up to (10.3) J/cm^2. The sheet resistance tends to saturate as the laser energy density increases still more up to (13) J/cm^2. The lowest sheet resistance obtained with (Al) dopant ~640 Ω / □ , about 2/3 of the substrate at laser flunce (11.54) J/cm^2.

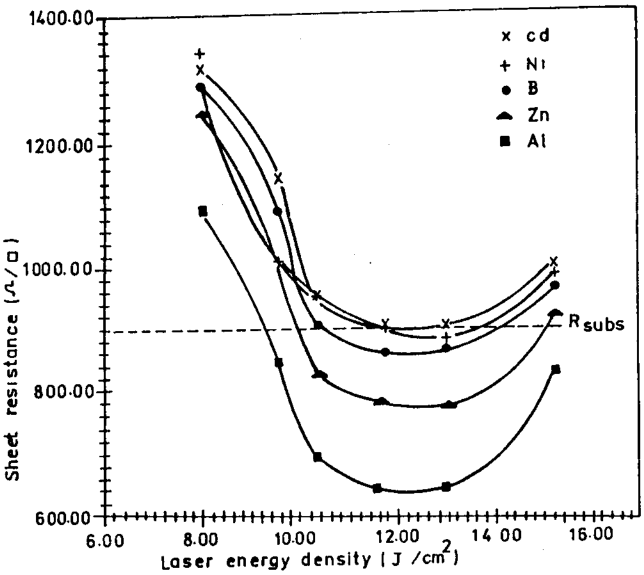

Fig. (3) Variation of the sheet resistance versus laser energy density

For energy density higher than (13) J/cm2 the sheet resistance increases with energy density.

Figure (4) shows the annealing laser enery density dependence of sheet resistance. All the curves pass through a minimum value at annealing flunce ~6.4 J / cm^2, with the sheet resistance obtained with (Al) impurity ~100 Ω/ □ about 1/4 of that obtained with (B) doping and 1/9 of the starting material. Figure (5) reveals the change in sheet resistance of Al-doped Ge (irradiated with 11.54 J/cm^2) by subsequentce annealing for (45 min.) at different annealing temperatures.

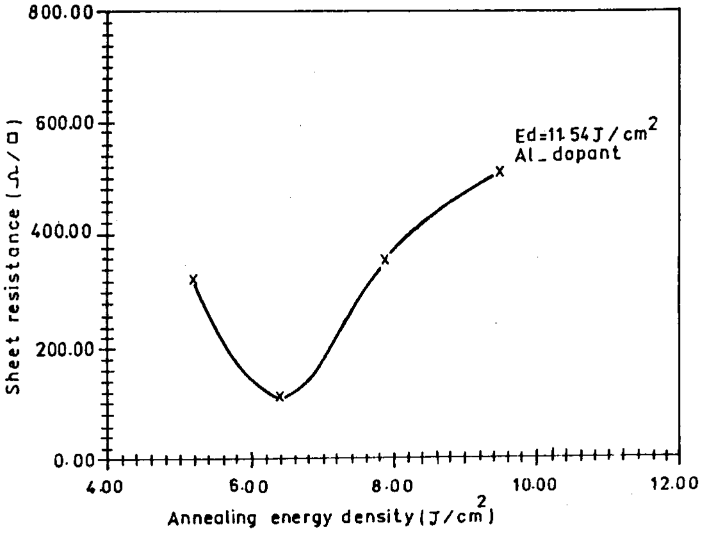

Fig. (4) Relationship between sheet resistance and laser annealing energy density.

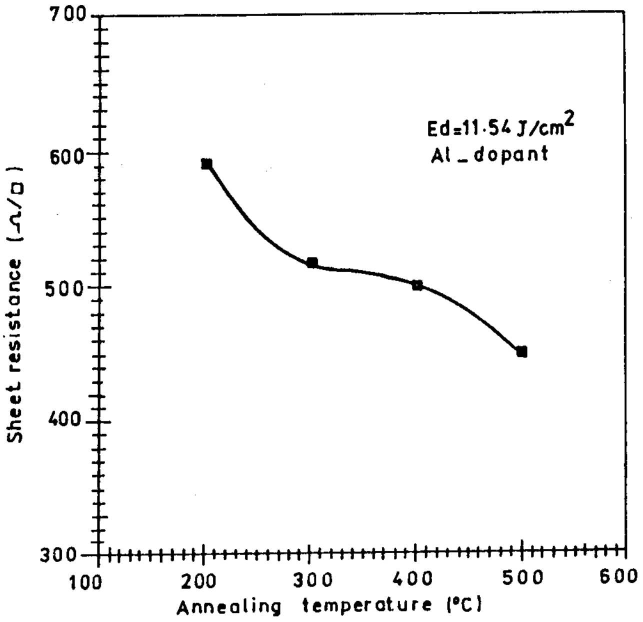

Fig. (5) Variation of the sheet resistance with annealing temperature.

Laser annealing is much more effective than thermal annealing. This is manifested particularly strikingly in a comparsion of the sheet resistance curves of the invesigated layers after laser and thermal annealing (Fig. (6)). The dependence of the sheet resistance on the applied electric field was investigated by irradiating the Ge sampls at a fixed flunce (11.54) J/cm^2.

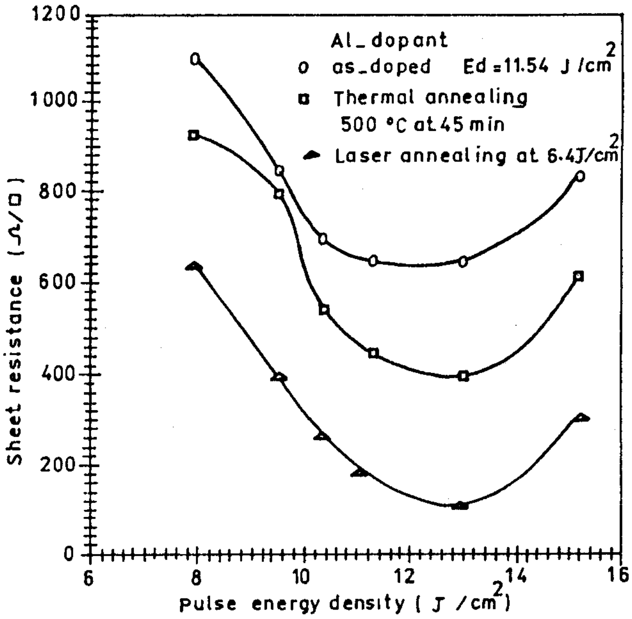

Fig. (6) Effect of annealing conditions on sheet resistance.

The results of (Al) doping expressed in terms of sheet resistance versus electric field, are displayed in Fig. (7) The dopant sloution temprature strongly affected the sheet resistance of the irradiated sample, this is clearly demonstrated in Fig. (8). The spatial uniformity of sheet resistance in laser doped germanium was monitored in Fig. (9).

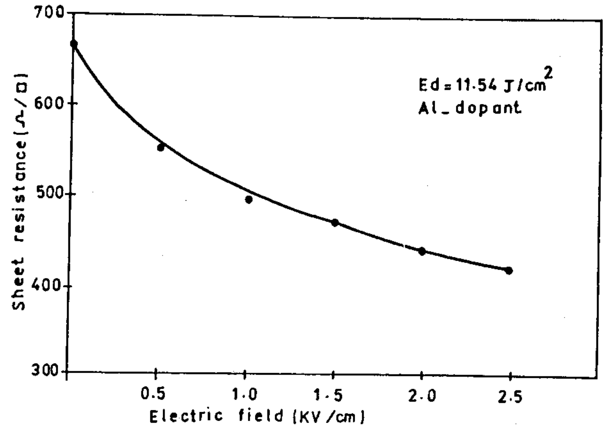

Fig. (7) Dependence of sheet resistance on applied electric field.

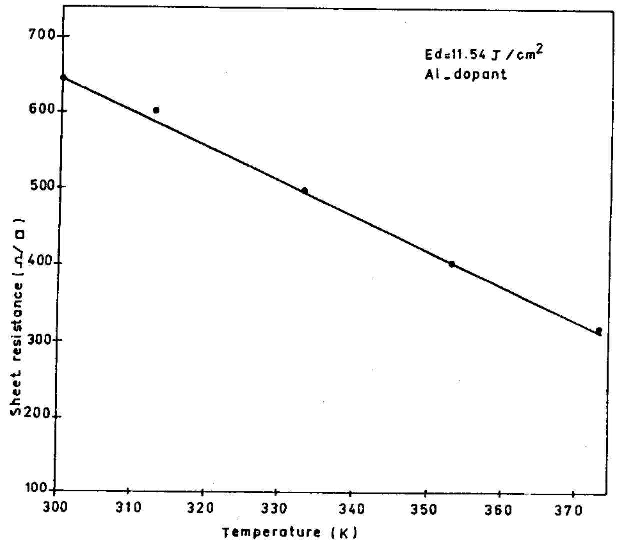

Fig. (8) Sheet resistance as afunction of solution temperature

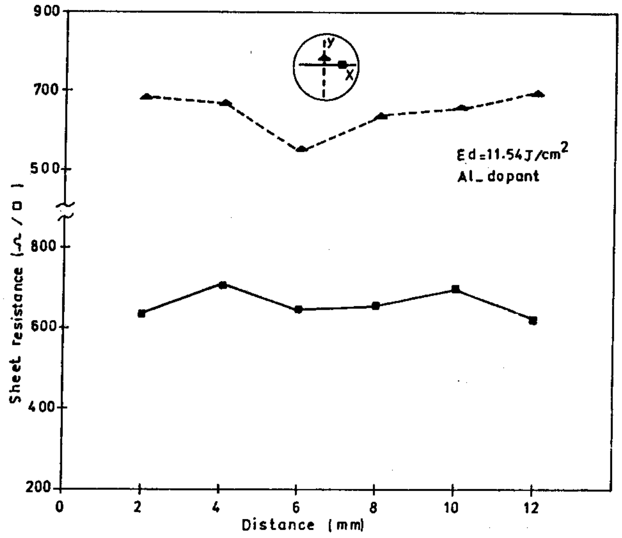

Fig. (9) measurment of sheet resistance across the irradiated area.

DISCUSSION

The resultes can be understood and accounted for if we include the following effects [8].

(1) In the laser-doping process, dopant atoms rapidly and uniformly diffuse from the surface throughout the molten region induced by laser beam.

(2) The diffusion of dopant in molten Ge occurs with a coefficient much higher than the diffusion coefficient of dopant in solids.

This allow us to ignore the diffusion of dopant in the solid region during laser treatment.

(3) The melt front moved faster than the dopant atoms diffused.

(4) At laser pulse energy density higher than the thrseshold energy density, the mechanism of laser doping changes drastically it become liquid-phase [9].
Our experiment indicates that at these energy densities a surface layer melt right down to ~25μm.

(5) The impurities having an interfacial distribution coefficient K<1. should accumulate at the sample surface. The amount of dopant accumulated at the surface should also increase with decreasing (K) [10].

The step rise of the curves at fluences below (9) J/cm^2, is probably due to the amorphousity of the Ge layer, according to earlier investigation of the processes of laser doping of Ge carried out by us [11,12].

The inceeasing of sheet resistance at energy density > 13 J/cm^2 is probably due to the overheating of the samples.

The low sheet resistance of Al-doped Ge is most probably due to the high solubility limit and low ionization energy [13].

The increases in electrical conductivity with laser annealing can be attributed both to an increase in thhe degree electrical activation of the dopant atoms and to an increase in the mobility of carriers because of the weaking of their scattering various lattice defects. Rising substrate temperature decreasing the laser flunce needed for doping and increasing the melting time and hence increasing diffusion depth [14].

We can suggest that the presence of electric field during laser irrdiation may induced high mobilities of vacancies and interstitials, thus annihilating one another and removing the displacement damage.

CONCLUSIONS

1 - In single steop laser doping of Ge, and if the laser has sufficient energy density at the substrate surface to cause a shallow melt phase (in which the dopant diffuse rapidly) subsequent cooling allows epitaxial regrowth to occur, incorporating the dopant on electrically active sites.

2 - Annealing of doped layer of Ge by laser and thermal furnace was accomplished by a considerable increase in the electrical conductance of annealed samples.

3 - Laser annealing is more effective than thermal anrealing. This is manifested strikingly particularly a comparsion of the sheet resistance of the investigated layer after laser and thermal annealing.

4 - With the assumption the carrier mobility is substantially constant for the various electric field, the sheet resistance curves shows the dependence of the carrier concentration on the electric field.

REFERNCES

[1] **Kareem, N- M.Sc. Thesis,** 1986; School of applied science, University of Technology, Baghdad - Iraq.

[2] **Affolter, K., W. Luthy,** and **Von Allmen,** 1978; "Properties of Laser - assisted doping in Sillcon", Appl, phys. Lett., 2 (2) : 185 .

[3] **Carey P. G., T. W. Sigmon, R. L. Press, and T. S. Fahien,** 1985. "Ultra - Shallow high - concentration Boron profiles for CMOS processing", IEEE Electron device Lett., vol. EDL - 6 (6) ; 291 .

[4] **Turner G. B., D. Tarrant, G. Pollock,** and R. Press, 1981. "Solar cells made by laser - induced diffusion directly from phosphine gas", Appl. phys. Lett, 39 (12) : 967 .

[5] **Stuck R., E. Fogarassy, T. C. Muller, M. Hodeau, A. Wattiaux,** and **P. Siffert,** 1981. "Laser - induced

diffusion by irradiation of silicon dipped into an organic solution of the dopant", Appl. phys. Lett., 38 (9), 715.

[6] **Deutsch T. F., D. J. Ehrlich, D. D. Rathman, D. J. Silvermith, and R. M. Osgood**, 1981. "Electrical properties of laser chemically doped Silicon", Appl. phys. Lett, 39 : 825 .

[7] **Ibbs K. G. , and M. L. Lloyed,** 1983. "Ultraviolet laser doping of Silicon", Opt. laser Technol., 15 : 35.

[8] **Sameshima T.,** and **S. Usui,** 1987."Analysis of dopant diffusion in molten silicon indused by a puised Excimer laser", Jap. J. Appl. phys., 26 (7) : 1208.

(9) **Narayan J., R. T. Young,** and **C. W. White,** 1978, "A Comparative study of laser and thermal annealing of Boron-implanted Silicon", J. Appl. phys., 49 (7), 3916.

(10) **Campisano U. U., P. Baeri, G. Foti, G. Ciavola,** and **E. Rimini,** 1980. "Impurity redistribution during laser Irradiation in Ion implanted Silicon", Radiation Effects, 48 187 .

(11) **Mousa A. M.,** and **R. A. Ismail,** "P-n junction formation in Ge dipped into Al2 (SO4)3 Solution by laser irradiation", J. Eng - & Tech. (in press).

(12) **Mousa A. M.,** and **R. A. Ismail,** "Structural studies of laser - induced doped Ge using X -ray diffraction". Turkish Journal of physics. (in press).

(13) **Hunter,** 1970, "Handbook of Semiconductor electronics", 3rd edition, p. (7-20).

(14) **Ong E., H. Chn,** and **S. Chen,** 1991, "Metal planarization with an Excimer laser" Sol. Stat. Technol., 34 (8) : 65 .