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# Effects of implantation temperature and thermal annealing on the $Ga^+$ ion beam induced optical contrast formation in a-SiC:H

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The effects of implantation temperature and post-implantation thermal annealing on the $Ga^+$ ion beam induced optical contrast formation in hydrogenated silicon–carbon alloy films have been studied. As a result of the implantation a well-expressed "darkening" effect (i.e. absorption edge shift to the longer-wavelength/lower-photon-energy region) has been registered. It is accompanied by a remarkable increase of the absorption coefficient up to 2 orders of magnitude in the measured photon energy range (1.5–3.1 eV). The optical contrast thus obtained (between implanted and unimplanted regions of the film material) has been made use of in the form of optical pattern formation by computer-operated $Ga^+$-focused ion beam. Possible applications of this effect in the area of submicron lithography and high-density optical data storage have been suggested with regard to the most widely spread focused micro-beam systems based on $Ga^+$ liquid metal ion sources. The fact that Ga has a very low melting point ($T_m = 29.8$ °C) and an unusual feature of volume contraction on melting are factors which favour Ga incorporation upon ion-implantation as dispersed clusters, or small nanoparticles. It has been previously noted that Ga precipitation into nanoparticles can vary dramatically (in terms of particle size) with Ga concentration and small changes in surface implant temperature, thus affecting the optical properties of the target. The precise role of implantation temperature effects, i.e. the target temperature during $Ga^+$ ion irradiation, on the optical contrast obtainable, has been therefore a key part of this study. Appropriate post-implantation annealing treatments were also studied, since these are expected to offer further benefits in reducing the required ion dose and enhancing contrast, thus increasing the cost-effectiveness of the bit-writing method.



## 1. Introduction

The present work is concerned with a new approach to providing ultra-stable (>50 years), ultra-high density (>1 Tbit/sq.in.) data storage for archival applications. We used ion-implantation to write nanoscale data into hydrogenated amorphous silicon carbide (a-SiC:H) films [1–7]. The role of implantation conditions and post-implantation treatments on the achievable data density and readout contrast was studied at present, aiming to determine optimised conditions. The use of gallium as the ion implanted species is attractive since it is available in standard focused ion beam (FIB) machines, and in addition has been shown to be capable of generating large optical contrasts [8,9]. The fact that Ga has a very low melting point ($T_m = 29.8$ °C) and an unusual feature of volume contraction on melting are factors which favour Ga incorporation upon ion-implantation as dispersed clusters, or small nanoparticles. It was previously noted that Ga precipitation into nanoparticles can vary dramatically (in terms of particle size) with Ga concentration and small changes in surface implant temperature [10,11]. The precise role of implantation temperature effects, i.e. the target temperature during $Ga^+$ ion irradiation, on the optical contrast obtainable, has been therefore a key part of this study. Appropriate post-implantation annealing treatments were also studied, since these are expected to offer further benefits in reducing the required ion dose and enhancing contrast, thus increasing the cost-effectiveness of the bit-writing method.

$Ga^+$ broad-beam ion-implantation in a-SiC:H samples was carried out at different substrate temperatures ($T_1$ = RT (room temperature), $T_2 = LN_2$ (liquid nitrogen), and $T_3 = +50$ °C) and some of the RT implanted samples were annealed post-implantation at

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**Table 1**
Thicknesses of a-SiC:H films $Ga^+$ ion implanted at RT.

| No. | Sample | *d* (nm) |
|---|---|---|
| 1 | X1REF | 200 |
| 2 | X1T1D1 | 200 |
| 3 | X1T1D2 | 200 |
| 4 | X1T1D3 | 180 |
| 5 | X1T1D4 | 140 |
| 6 | X1T2D1 | 200 |
| 7 | X1T2D2 | 195 |
| 8 | X1T2D3 | 105 |
| 9 | X2REF | 170 |
| 10 | X2T1D1 | 170 |
| 11 | X2T1D2 | 170 |
| 12 | X2T1D3 | 150 |
| 13 | X2T1D4 | 110 |
| 14 | X2T2D1 | 170 |
| 15 | X2T2D2 | 165 |
| 16 | X2T2D3 | 90 |

higher temperatures in vacuum. The expected benefit for the optical data storage method, which relies for readout on reduced optical transmission detected by scanning near-field optical microscopy (SNOM) [12,13], was that a lower implantation temperature would result in an increased amount of defects leading to an absorption increase, and hence further decrease in transmission (greater readout contrast). The expected effect of higher implantation temperatures, or high temperature post-implantation annealing, was that there would be an increase in the optical reflectivity and decrease in transmission due to Ga clusters coalescing into bigger Ga colloids.

## 2. Experimental

Wide bandgap a-$Si_{1-x}C_x$:H ($x_1$ = 0.18; $x_2$ = 0.35) thin film samples were deposited onto Corning glass substrates by RF (13.56 MHz) reactive magnetron sputtering. A composite target, composed of

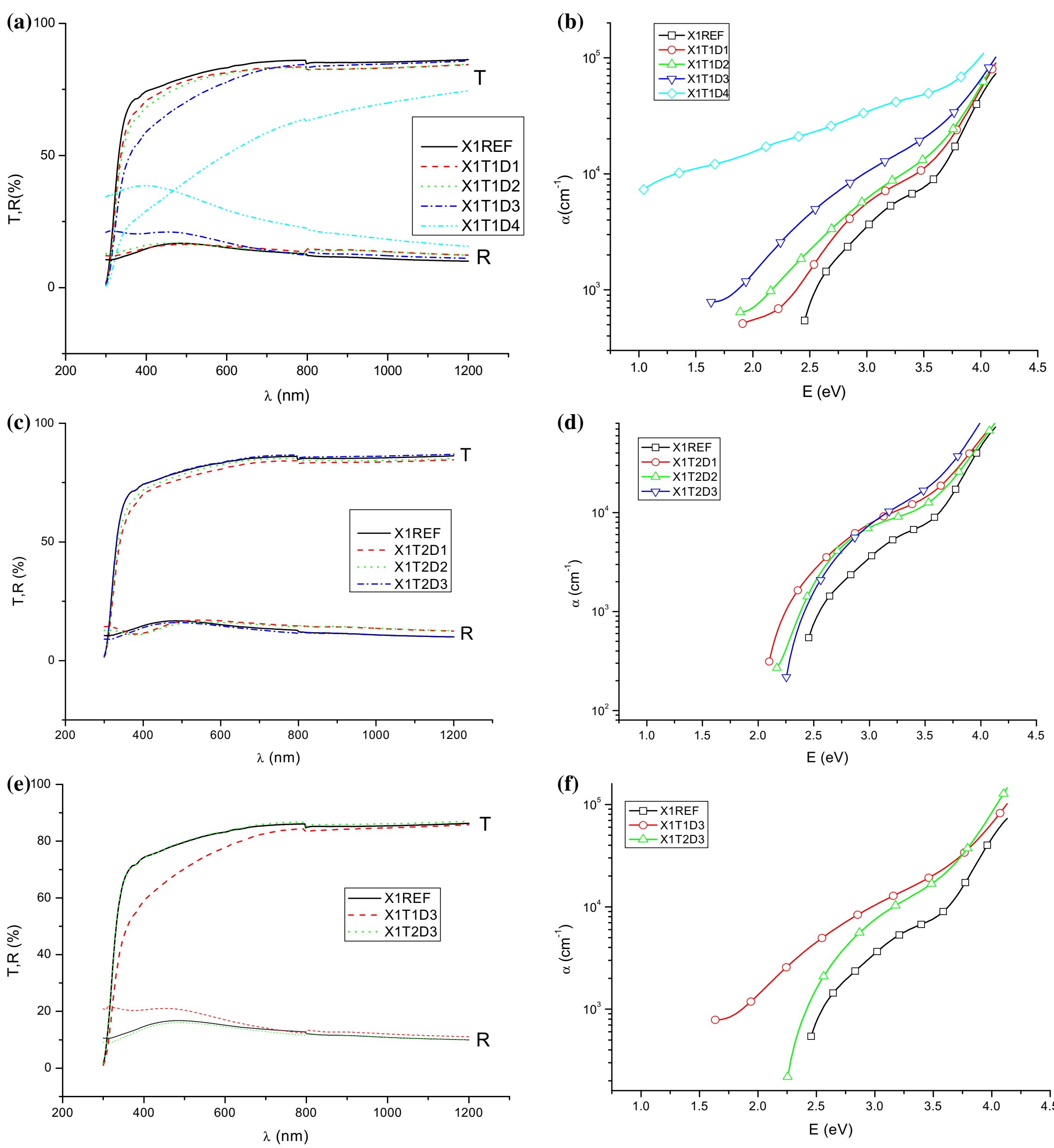


**Fig. 1.** Transmission (T) and reflection (R) (a, c and e), and absorption coefficient α (b, d and f) of $Ga^+$ implanted a-$Si_{1-x}C_x$:H ($x_1$ = 0.18) films with different doses: $D_1 = 1 \times 10^{15}$ cm$^{-2}$, $D_2 = 5 \times 10^{15}$ cm$^{-2}$, $D_3 = 2.5 \times 10^{16}$ cm$^{-2}$ and $D_4 = 1.25 \times 10^{17}$ cm$^{-2}$ (last dose only at RT).