Doping effects on minority-carrier lifetimes in ultrananocrystalline diamond/hydrogenated amorphous carbon composite films

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1. Introduction

Ultrananocrystalline diamond (UNCD)/hydrogenated amorphous carbon (a-C:H) composite (UNCD/a-C:H) films possess specific characteristics as follows: (a) the appearance of additional energy levels in diamond bandgap [1]; and (b) large absorption coefficients ranging from visible to ultraviolet [2], both of which might be due to large number of grain boundaries between UNCD grains and those between UNCD grains and a-C:H [1,3]. Owing to the above-mentioned specifics, UNCD/a-C:H films are expected to be applied to photovoltaics such as UV sensors. Actually, we have fabricated pn heterojunction diodes comprising UNCD/a-C:H films and Si substrates, and confirmed their photocurrents [4,5]. Although the minority-carrier lifetime is an important factor for photovoltaics, it has never been studied for UNCD/a-C:H. In this work, we experimentally measured the minority carrier lifetimes for typical samples.

2. Experimental

Films were prepared on insulating Si substrates by coaxial arc plasma deposition (CAPD) with graphite targets [6]. p-Type films were deposited with 1, 5, 10 at. % boron-doped graphite targets, which resulted in 0.5, 3, 7 at. % boron content in the films respectively. n-Type films were prepared at nitrogen and hydrogen mixed-gas inflow ratios of 0.3, 1, and 1.5, which resulted in the formation of 4, 6, 8 at. % nitrogen-doped films, respectively. The minority-carrier lifetime was measured by a μ-PCD apparatus.

3. Results and Discussion

The time-decay of the minority-carrier lifetime follows the following equation:

$$\rho_{p,n,i} = \rho_{p,n,i}(0)\exp\left(\frac{t}{\tau_{n,p}}\right) + \rho_{p0,n0} \ ,$$

where ρ and τ are the carrier density and minority-carrier lifetime, and subscripts p, n, and i indicate p-type, n-type, and intrinsic, respectively. The minority-carrier lifetime was estimated from decay curves as shown in Fig. 1. τ of the undoped film was estimated to be 1.58 μs. τ of 0.5, 3, and 7 at. % boron-doped films were 0.98, 1.04, and 0.86 μs, respectively. On the other hand, τ of 4, 6, 8 at. % nitrogen-doped films were approximately 0.3 μs. The nitrogen-doped films have smaller minority carrier lifetime values than those of boron doped films.

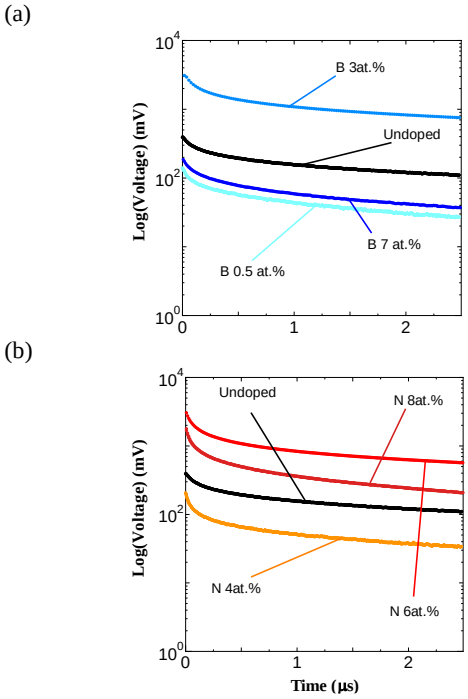

Fig. 1. Time-decay curves of carrier density in voltage of (a) undoped and boron-doped films and (b) nitrogen-doped films.

From our previous studies, doped boron and nitrogen seem to replace hydrogen atoms that terminate dangling bonds at grain boundaries [4,7]. Whereas doped boron atoms hardly degrade the lifetime, doped nitrogen atoms evidently shorten the lifetime.

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