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Highly Doped Nano-crystal Embedded Polymorphous Silicon Thin Film Deposited by Using Neutral Beam Assisted CVD at Room Temperature

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The promise of nano-crystalites (nc) as a technological material, for applications including display backplane, and solar cells, may ultimately depend on tailoring their behavior through doping and crystallinity. Impurities can strongly modify electronic and optical properties of bulk and nc semiconductors. Highly doped dopant also effect structural properties (both grain size, crystal fraction) of nc-Si thin film. As discussed in several literatures, P atoms or radicals have the tendency to reside on the surface of nc. The P-radical segregation on the nano-grain surfaces that called self-purification may reduce the possibility of new nucleation because of the five-coordination of P. In addition, the P doping levels of $\sim 2\times10^{21}$ at/cm^3 is the solubility limitation of P in Si; the solubility of nc thin film should be smaller. Therefore, the non-activated P tends to segregate on the grain boundaries and the surface of nc. These mechanisms could prevent new nucleation on the existing grain surface. Therefore, most researches shown that highly doped nc-thin film by using conventional PECVD deposition system tended to have low crystallinity, where the formation energy of nucleation should be higher than the nc surface in the intrinsic materials. If the deposition technology that can make highly doped and simultaneously highly crystallized nc at low temperature, it can lead processes of next generation flexible devices.

Recently, we are developing a novel CVD technology with a neutral particle beam (NPB) source, named as neutral beam assisted CVD (NBaCVD), which controls the energy of incident neutral particles in the range of 1~300eV in order to enhance the atomic activation and crystalline of thin films at low temperatures. During the formation of the nc-/pm-Si thin films by the NBaCVD with various process conditions, NPB energy directly controlled by the reflector bias and effectively increased crystal fraction (～80%) by uniformly distributed nc grains with 3～10 nm size. In the case of phosphorous doped Si thin films, the doping efficiency also increased as increasing the reflector bias (i.e. increasing NPB energy). At 330V of reflector bias, activation energy of the

doped nc-Si thin film reduced as low as 0.001 eV. This means dopants are fully occupied as substitutional site, even though the Si thin film has nano-sized grain structure. And activated dopant concentration is recorded as high as up to 1020 $\#/cm^3$ at very low process temperature (<80°C) process without any post annealing. Theoretical solubility for the higher dopant concentration in Si thin film for order of 1020 $\#/cm^3$ can be done only high temperature process or post annealing over 650°C. In general, as decreasing the grain size, the dopant binding energy increases as ratio of 1 of diameter of grain and the dopant hardly be activated. The highly doped nc-Si thin film by low-temperature NBaCVD process had smaller average grain size under 10 nm (measured by GIWAXS, GISAXS and TEM analysis), but achieved very higher activation of phosphorous dopant; NB energy sufficiently transports its energy to doping and crystallization even though without supplying additional thermal energy.

TEM image shows that incubation layer does not formed between nc-Si film and SiO2 under later and highly crystallized nc-Si film is constructed with uniformly distributed nano-grains in polymorphous tissues. The nucleation should be start at the first layer on the SiO2 later, but it hardly growth to be cone-shaped micro-size grains. The nc-grain evenly embedded pm-Si thin film can be formatted by competition of the nucleation and the crystal growing, which depend on the NPB energies.

In the evaluation of the light soaking degradation of photoconductivity, while conventional intrinsic and n-type doped a-Si thin films appeared typical degradation of photoconductivity, all of the nc-Si thin films processed by the NBaCVD show only a few % of degradation of it. From FTIR and RAMAN spectra, the energetic hydrogen NB atoms passivate nano-grain boundaries during the NBaCVD process because of the high diffusivity and chemical potential of hydrogen atoms.

Keywords: NBaCVD, nano-crystalline silicon, room temperature, doping, stability