Ionic Amorphous Oxide Semiconductors: material design and device application

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Attraction of semiconductor is controllability of carrier electrons over several orders of magnitude in a dynamic range. On the other hand, amorphous material has inevitable process advantages, i.e., homogeneous films can be deposited on a large area of various substrates at low temperature. Research of amorphous semiconductors started to seek materials which meet both of these advantages. Amorphous oxide semiconductor has a long history since the first report on glassy semiconductors based on V_2O_5-P_2O_5 by a Denton in 1954. However, electrical performance these glassy semiconductors are poor (low conductivity and mobility) due to variable range hopping. As a consequence, no application has been performed.

In 1995~2002, we reported a series of transparent amorphous oxide semiconductors created by deposition from gas-phase such as PLD and sputtering along with material design concept based on a simple consideration about chemical bonding. The electron mobility of these amorphous materials such as CdO-GeO_2 and $InGaZnO_4$ is of the order of 10 $cm^2(Vs)^{-1}$ and comparable to that in the corresponding crystalline phases. This is totally different from the situation in conventional amorphous semiconductors. For instance, mobility of a-Si:H , ~1$cm^2(Vs)^{-1}$, is less by 2 orders of magnitude than that of c-Si compared at a carrier concentration $10^{19}cm^{-3}$.

We fabricated field-effect transistor on plastic substrate utilizing a-$InGaZnO_4$ as an active layer at room temperature [1]. The field-effect mobility in the transistor is >10$cm^2(Vs)^{-1}$, which is larger by an order of magnitude than that in FET based on a-Si:H or organic molecules. Electronic circuit formed on plastics is called flexible electronics. FET is an elementary building block of electronic circuits and FET on plastic substrate is extensively studied using various organic semiconductors. However, the performance and chemical stability of organic semiconductors are rather poor compared with amorphous oxide semiconductors. The present amorphous oxide semiconductor is featured by high ionic bond nature. The Fermi-level is controllable from the mid gap (variable range hopping) to above the mobility edge (band conduction). A P-type amorphous oxide was also found in ZnO-Rh_2O_3 and PN-diode composed of all amorphous oxide semiconductors with a reasonably good performance was realized [2].

In this talk we review the recent progress of amorphous oxide semiconductors and device application.

[1]Nature 432,488(2004), [2] Adv.Mater. 17,1409(2003).