Investigation of earth-abundant photovoltaic material Zn3P2 nanostructures using electron microscopy

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Background incl. aims

Earth-abundant semiconductor material Zn_3P_2 is a promising alternative for photovoltaic applications. Unfortunately, there are not many suitable substrates for Zn_3P_2 nanostructure growth as it is difficult to find a lattice parameter and thermal expansion coefficient matching material. Therefore, growth of defect-free Zn_3P_2 nanostructures has been proven to be challenging as it tends to form defects during growth which results in poor crystal quality thus is detrimental for photovoltaic applications.[1][2] To minimize the number of defects, a new method of Zn_3P_2 growth is needed. Selected Area Epitaxy (SAE) and Vapour-Liquid-Solid (VLS) have been shown to be effective techniques in producing different morphologies of Zn_3P_2: nanowires, nanopyramids and thin films.[3] Both techniques reduce the interfacial area which is key in limiting defect formation. In both VLS and SAE indium has been utilized as a seed particle or the substrate (InP). By exchanging In for more earth-abundant Sn seed particles for VLS and InP substrate for Si, it would be possible to completely remove In from the growth process. It is also important to investigate high throughput methods of producing Zn_3P_2 nanostructures for possible future industrial scalability.

Methods

Metal organic vapour phase epitaxy (MOVPE) is an appealing method for growth of SAE and VLS Zn_3P_2. MOVPE is an epitaxy method that has a high through-put and is widely used in industry for manufacturing compound semiconductor devices. InP substrates have been used in our experiments with a silicon oxide (SiO_2) mask that was patterned by EBL to try and identify preliminary growth parameters for SAE growth. Growth times, temperature and precursor flows have been varied to try and find optimal conditions for Zn_3P_2 growth with minimal parasitic nucleation on the SiO_2 mask. For SAE patterning, displacement Talbot lithography (DTL) which is a lithography technique that uses collimated monochromatic light to create a periodic pattern on the substrate, was used. Moving away from EBL to DTL is a key step for scalability of Zn_3P_2 growth, as DTL can pattern much larger areas quicker. Si substrates were used for DTL dose and pattern testing. Sn seed particles on InP substrate for VLS growth were used. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) were used to image and investigate the morphology and growth selectivity of the resulting Zn_3P_2 structures. Scanning TEM (STEM) together with x-ray energy dispersive spectroscopy (XEDS) was used to image and acquire compositional data of the nanowires.

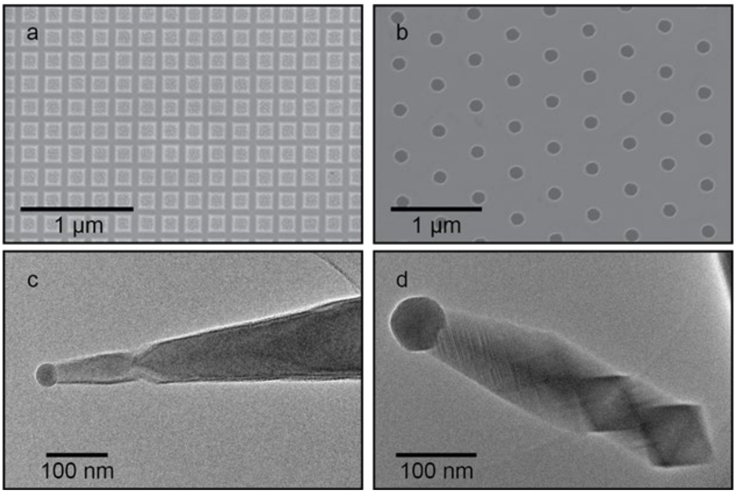
Results

SAE Zn_3P_2 pyramidal structures by MOVPE on InP substrate were successfully grown (Fig.1a). By optimizing the precursor flows and temperature we were able to minimize most of the parasitic nucleation on the SiO_2 mask layer. DTL was used to pattern hexagonal pattern of holes on SiO_2 on Si substrates, which have diameter of 180nm-200nm and pitch of 500nm (Figure 1b). Sn seeded Zn_3P_2 nanowires were grown and then transferred to a TEM copper grid (Fig. 1 c-d). Additional compositional analysis of the nanowires was performed using XEDS coupled with STEM.

Conclusion

We have shown that growth of SAE Zn_3P_2 on InP substrate is possible using MOVPE. By optimizing the growth conditions parasitic growth is minimized on the mask. Si substrates were patterned by using DTL and desired size and pitch of the nanoholes was achieved. Nanowires were successfully grown by using Sn instead of In seed particles. We hope to exchange InP for Si thus removing any scarce elements from the production and enabling full scalability of Zn_3P_2 nanostructures. Future experiments will focus on realizing SAE Zn_3P_2 growth on the patterned Si substrates and exploring Si substrates for Sn seeded VLS nanowire growth.

Graphic:



Keywords:

Zn3P2 Earth-Abundant SAE VLS SEM

Reference:

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