THE USE OF II-VI COMPOUNDS IN THE ELECTRONIC APPLICATIONS

Serafettin EREL, H. Ali CETINKARA, Erdogan GOÇER

Department of Physics, Faculty of Science and Letters, University of Kirikkale, 71450 Yahşihan / Kirikkale / TURKEY

ABSTRACT

This paper presents new and possible industrial applications of II-VI semiconductor compounds. In the recent years, wide gap II-VI compounds have considerably been utilised in the electronic applications. Having higher optical transition probabilities for absorption and luminescence, higher ionicity, smaller radiative lifetime, II-VI semiconductor materials such as CdS, CdSe, CdTe, ZnS, ZnSe, ZnO, have been capable of emitting every colour of the visible spectrum in the LED production. Moreover, the information transfer devices, solar energy converters, photoreisitors, X-ray detectors and also electron beam screens have been the domain of II-VI compounds, because these materials can be produced to a high standard of purity from inexpensive and available raw materials. II-VI compounds can be produced in the form of polycrystalline layers of good optical quality by means of convenient and cheap methods as well. The surfaces and interfaces of these compounds are commonly rather stable. Because of that these semiconductors have been seen as significant rival materials against elemental other group semiconductor compounds.

I. INTRODUCTION

Important researches have been focused on II-VI compounds since the late 1950s. Because of their superiority to their rival materials, these compounds are getting more of importance day by day in the research for electronic materials. About these materials many experimental procedures have been improved and also theoretical models have been developed. However, in spite of their positive properties, crystallographic properties of the some II-VI semiconductor materials (e.g. ZnS) have been hindered due to polytypism in the electronic industry. About optoelectronic applications of the semiconductor materials significant studies have been done [1-8]. Utilising II-VI compounds thin film-based photoelectrochemical solar cells have been improved [9] and also band gap determination and magneto resistance of the compounds have been researched by means of typical methods [10-13]. Moreover, using sometype of II-VI compounds green light emitting diodes have been produced [14] and multi-quantum wells of the low-dimensional heterostructures based on the compounds have been studied [15-21]. The studies produced by II-VI compounds have semiconductor materials, which have

<table>
<thead>
<tr>
<th>Compound</th>
<th>Energy gap (eV)</th>
<th>Type of transition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ge</td>
<td>0.67</td>
<td>Indirect</td>
</tr>
<tr>
<td>Si</td>
<td>1.11</td>
<td>Indirect</td>
</tr>
<tr>
<td>GaAs</td>
<td>1.43</td>
<td>Direct</td>
</tr>
<tr>
<td>GaP</td>
<td>2.30</td>
<td>Direct</td>
</tr>
<tr>
<td>CdSe</td>
<td>1.73</td>
<td>Direct</td>
</tr>
<tr>
<td>ZnTe</td>
<td>2.25</td>
<td>Direct</td>
</tr>
<tr>
<td>CdS</td>
<td>2.42</td>
<td>Direct</td>
</tr>
<tr>
<td>ZnSe</td>
<td>2.67</td>
<td>Direct</td>
</tr>
<tr>
<td>ZnS</td>
<td>3.66</td>
<td>Direct</td>
</tr>
</tbody>
</table>

According to physical properties these compounds have been utilised in the different applications.

2. RESULTS AND DISCUSSION

II-VI compounds have been utilised mainly from a choice of the techniques complex. Because of that some of the optoelectronic properties also some of them are thin-film-based and various growth techniques such as molecular beam epitaxy, molecular beam deposition, (VPE, CVD, OM-CVD), liquid phase epitaxy, flash evaporation, and pyrolysis, have significantly been used. Hot wall epitaxy are the new prod...
been studied [15-21]. The studies of the quantum dots of the semiconductor materials produced by II-VI compounds have also been seen very significantly [22-23]. Some of the semiconductor materials, which have technological importance, are seen in Table-1.

**Table 1. Some of the technologically important semiconductors and II-VI compounds [1].**

<table>
<thead>
<tr>
<th>Compound</th>
<th>Energy gap (eV)</th>
<th>Type of transition</th>
<th>Mobility (cm²V⁻¹s⁻¹)</th>
<th>Effective mass</th>
<th>Ionicity</th>
<th>Lifetime (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ge</td>
<td>0.67</td>
<td>Indirect</td>
<td>4000</td>
<td>1.58, 0.08</td>
<td>0</td>
<td>$10^4$</td>
</tr>
<tr>
<td>Si</td>
<td>1.11</td>
<td>Indirect</td>
<td>1500</td>
<td>0.91, 0.19</td>
<td>0</td>
<td>$10^3$</td>
</tr>
<tr>
<td>GaAs</td>
<td>1.43</td>
<td>Direct</td>
<td>9000</td>
<td>0.065</td>
<td>0.31</td>
<td>$10^8$</td>
</tr>
<tr>
<td>GaP</td>
<td>2.30</td>
<td>Indirect</td>
<td>180</td>
<td>0.35</td>
<td>0.33</td>
<td>$10^7$</td>
</tr>
<tr>
<td>CdSe</td>
<td>1.73</td>
<td>Direct</td>
<td>650</td>
<td>0.13</td>
<td>0.70</td>
<td>$&lt;10^9$</td>
</tr>
<tr>
<td>ZnTe</td>
<td>2.25</td>
<td>Direct</td>
<td>100</td>
<td>0.11</td>
<td>0.61</td>
<td>$&lt;10^9$</td>
</tr>
<tr>
<td>CdS</td>
<td>2.42</td>
<td>Direct</td>
<td>350</td>
<td>0.20</td>
<td>0.69</td>
<td>$&lt;10^9$</td>
</tr>
<tr>
<td>ZnSe</td>
<td>2.67</td>
<td>Direct</td>
<td>200</td>
<td>0.17</td>
<td>0.63</td>
<td>$&lt;10^9$</td>
</tr>
<tr>
<td>ZnS</td>
<td>3.66</td>
<td>Direct</td>
<td>150</td>
<td>0.28</td>
<td>0.62</td>
<td>$&lt;10^9$</td>
</tr>
</tbody>
</table>

According to physical properties of II-VI compounds shown in Table-1, these materials have been utilised in the different application fields.

**2. RESULTS AND DISCUSSION**

II-VI compounds have been utilised both in the form of crystals and thin film layers. The choice of the techniques completely depend on where the electronic goods will be used. Because of that some of the optoelectronic part of the electronic devices are crystal-based and also some of them are thin-film-based. So, in the production crystal of II-VI compounds various growth techniques such as vapour, melt, hydrothermal, solution and flux growths have been utilised very effectively. Meanwhile, in the production of thin layers of II-VI compounds on the suitable substrates different techniques, such as vapour phase epitaxy (VPE, CVD, OM-CVD), liquid phase epitaxy, molecular beam epitaxy, thermal vacuum evaporation, flash evaporation, cathodic sputtering, electron-beam evaporation and spray pyrolysis, have significantly been used. Moreover, the methods of the atomic layer epitaxy and hot wall epitaxy are the new production techniques used in this area.
Current application areas of II-VI compounds in the electronic industry

Most of II-VI semiconductor materials have been used extensively in the industry because of their physical properties. These application areas of the compounds are given in Table-2.

Table-2. Illustrates the current application areas of some II-VI compounds [1].

<table>
<thead>
<tr>
<th>Application fields</th>
<th>The used materials</th>
<th>Optimum active surface area of the component</th>
<th>Material preparation techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorber material for solar cells</td>
<td>CdTe</td>
<td>10-100 cm²</td>
<td>Vacuum evaporation; VPE (CVT, CSVT, CVD); sintering</td>
</tr>
<tr>
<td>ac,dc electroluminescent thin film displays</td>
<td>ZnS, ZnSe, ZnS₅Se₁ₓ</td>
<td>&gt;10 cm²; &lt;200 cm²</td>
<td>Vacuum evaporation, cathodic sputtering; VPE</td>
</tr>
<tr>
<td>ac,dc electroluminescent powder displays</td>
<td>ZnS, Zn₆Cd₆₋ₓS</td>
<td>&lt;100 cm²</td>
<td>Settling process</td>
</tr>
<tr>
<td>Window material for solar cells</td>
<td>CdS, Zn₆Cd₆₋ₓS</td>
<td>10-100 cm²</td>
<td>Vacuum evaporation, cathodic sputtering; VPE (CVT, CSVT, CVD); spray pyrolysis</td>
</tr>
<tr>
<td>Laser window material</td>
<td>ZnSe, CdTe</td>
<td>&gt;1 cm²</td>
<td>Melt growth, vapour growth (seed methods)</td>
</tr>
<tr>
<td>Photovoltaic detectors</td>
<td>p-InO/n-CdS, p-CulnSe₂/n-CdS, p-GaAs/n-ZnSe, etc.</td>
<td>&lt;1 cm²</td>
<td>Vacuum evaporation, vapour phase epitaxy VPE (sublimation, CVT, CSVT, CVD)</td>
</tr>
<tr>
<td>Photoresistors, photoconductive detectors</td>
<td>CdS, CdSe, CdS₅Se₁ₓ₋ₓ (Zn₆Cd₆₋ₓS)</td>
<td>&lt;10 cm²</td>
<td>Vacuum evaporation, cathodic sputtering, spray deposition; sintering Settling process</td>
</tr>
<tr>
<td>Cathode ray tube screens</td>
<td>ZnS, Zn₅S₅Cd₆₋ₓS</td>
<td>400-5000 cm²</td>
<td></td>
</tr>
<tr>
<td>Projection colour television</td>
<td>ZnS, Zn₅S₅Cd₆₋ₓS</td>
<td>400-5000 cm²</td>
<td>Melt growth, vapour growth (seed methods)</td>
</tr>
<tr>
<td>Light emitting diodes</td>
<td>ZnS, Zn₅S₅Cd₆₋ₓS</td>
<td>&lt;1 cm²</td>
<td>All growth methods which provide single crystalline sample</td>
</tr>
<tr>
<td>Optical waveguides and modulators</td>
<td>ZnO, ZnS</td>
<td>~1 cm²</td>
<td>Cathode sputtering, vacuum evaporation; VPE (sublimation, CVT)</td>
</tr>
<tr>
<td>Bulk-modulators and switches</td>
<td>ZnS, CdS</td>
<td>&gt;1 cm²</td>
<td>Melt growth; vapour growth</td>
</tr>
</tbody>
</table>

Using different production methods, these II-VI compounds find different application areas in the electronic industry from to product colour television to cathode ray tube screen. From goods to goods, various parameters and techniques play important role in optimizing properties of II-VI compounds, which are as follows:

Advantages

- From inexpensive and readily available to a high standard with purity.
- They can be produced in thin film form, convenient and cheap method of producing semiconductor materials which are based on minority carriers.
- Their surface and interface recombination velocity is low.
- Most of these compounds are covered by a continuous valence conduction band.

Disadvantages

- Comparing to III-V compounds, they are complex and costly.
- Relating to the control of production, less knowledge and experience.
- Any device based on thin film must have specific requirements.

Concerning these properties, there is always a potential for II-VI compound to be a candidate for electronic materials both for current and future technology.

3. CONCLUSION

Finding very wide industrial applications of II-VI compounds is hindered in order to use in the near future, some of their physical properties. High degree of defects can be thought as a stumbling block in these compounds, new kind of techniques, such as...
goods to goods, various parameters such as size, crystallographic properties, production techniques play important role in the use of these compounds. Concerning the physical properties of II-VI compounds, advantages and disadvantages of these materials can be seen as follows;

Advantages

- From inexpensive and readily available raw materials, these compounds can be produced to a high standard with purity.
- They can be produced in the form of polycrystalline layers of good optical quality by convenient and cheap methods. The crystallite dimensions of these layers are of the order of the minority carrier diffusion length, a condition essential for all device applications which are based on minority carrier effects.
- Their surface and interfaces are commonly rather stable involving a rather low surface recombination velocity.
- Most of these compounds are readily miscible allowing the whole visible spectrum to be covered by a continuous variation of the band gap.

Disadvantages

- Comparing to III-V compounds and Ge and Si, to produce of bulk crystals is more complex and costly.
- Relating to the control of native defects and impurities and their electrical and optical properties, less knowledge is available.
- Any device based on p/n junction has not be produced using II-VI compounds up to now. Concerning these properties of II-VI compounds, they have been seen very significant electronic materials both for current and also future industrial applications.

3. CONCLUSION

Finding very wide industrial application, so far some kinds of II-VI compounds have been hindered in order to use in the production of some "high-tech goods" because of their some physical properties. High degree of self-compensation of incorporated acceptors by native defects can be thought as a significant hinder in this matter. Nevertheless, concerning the new kind of techniques, such as the technique of Ion implantation, can be the last hope in the
production of high-tech goods based on II-VI compounds. Making a positive approach, to produce of II-VI based-blue diode laser and blue-green light emitting diodes can be thought in this area. Because to produce p/n junction utilising II-VI compounds has been one of the most attention during the last two decades.

REFERENCES

[4]- Choi, In-Hwan; Eom, Sung-Hwan; Dispersion of birefringence in AgGaS2 and CuGaS2, Journal of Applied Physics, Vol. 82, 1997, p 3100
[12]- Oshikiri,M., Arayasetiwyan,F.; Band gaps and quasiparticle energy calculations on ZnO, ZnS, and ZnSe in the zinc-blende structure by the GW approximation; Physical review. B, Condensed matter, 1999, Vol.60, No.15, pp.10754-10757
Making a positive approach, to emitting diodes can be thought
compounds has been one of the

9, North-Holland Publishing
ded electron microscopy and
ments on the III-VI diluted
sis, Vol.83;1998, p 6557
ence in AgGaS2 and CuGaS2,
memory in two-dimensional
e diode lasers, Contemporary
emitting diodes promise full-
ZnCdSe and ZnsCdMg1-x-
Vol. 84, 1998, p.1472
P; Comparative study of
etrical solar cells; Solar
ation of band offsets, optical
al of applied physics, 2000,
dermination of semiconductor
plied physics, 1999, Vol.86,
energy calculations on ZnO,
simulation; Physical review. B,
ials at high pressures; SPIE
diodes with long lifetime on
-189
S, Ghaemi,H., Assin,V.,
ization of patterned ZnCdSe
g diodes; Journal of vacuum
iter structures. Processing,
dev, L., VonDerOsten,W.,
and energy relaxation in

[17]-Kozlovsky,Vl., Sadofyev,YG.; Investigation of e-h pair compression in molecular beam
epitaxy grown ZnCdSe/ZnSe multiquantum wells at volume excitation by electron
beam; Journal of vacuum science & technology. B. Microelectronics and nanometer
structures. Processing, measurement and phenomena, 2000,Vol.18, No.3, pp.1538-1541
[18]-HernandezRamirez,LM., Hernandez,Calderon,1.; Resonant Raman scattering and
photoluminescence enhancement in ZnCdSe quantum wells; Journal of vacuum science &
technology. B. Microelectronics and nanometer structures. Processing, measurement and
phenomena, 2000, Vol.18, No.3, pp.1542-1544
[19]-Berry, JI., Knobel, R., Ray,O., Peoples,W., Samarth,N.; Modulation-doped
ZnSe/(Zn,Cd,Mn)Se quantum wells and superlattices; Journal of vacuum science &
technology. B. Microelectronics and nanometer structures. Processing, measurement and
phenomena,2000,Vol.18, No.3, pp.1692-1696
[20]-Lin,W., Tamargo,MC., Wei, HY., Sarney,W., SalamancaRiba,L., Fitzpatrick,BJ.;
Molecular-beam epitaxy growth and nitrogen doping of hexagonal ZnSe and ZnCdSe/ZnSe
quantum well structures on hexagonal ZnMgSSe bulk substrates; Journal of vacuum science &
technology. B. Microelectronics and nanometer structures. Processing, measurement and
phenomena, 2000, Vol.18, No.3, pp.1711-1715
Ishibashi,A.; Recombination lifetimes in undoped and doped ZnCdSe laser structures; SPIE
proceedings series,1999,Vol.3625, pp.41-48
[22]-Matsumura,N., Tai,E., Kimura,Y., Saito,T., Ohira,M., Saraie,J.; Self-assembling CdSe,
ZnCdSe and CdTe quantum dots on ZnSe(100) epilayers; Japanese Journal of Applied
Physics, Part I : Regular papers, short notes & review papers, 2000, Vol.39, No.3A, pp.1104-
1105.
[23]-Kaschner,A., Strassburg,M., Hoffmnn,A., Thomcsn,C., Bartels,M., Lischka,K.,
Schikora,D.; Temporal evolution of resonant Raman-scattering in ZnCdSe quantum dots;
Applied physics letters, 2000, Vol.76, No.19, pp.2662-2664