Marwadi University

Date: July 1, 2021

Office Order

Subject: Office order to depute Dr. Prashant Ghedia as postdoc visitor at Hasselt University, Belgium

Dr. Prashant Ghediya, Assistant Professor, Department of Physics, Faculty of Science, Marwadi University is deputed as postdoc visitor to oversaw the research activity of IMO-IMOMEC and to carry out the joint research project entitled 'USSC of new emerging materials for tandem devices' by Hasselt University, Belgium for 3 months (August to October 2021) under the superstition of Associate Professor Wim Deferme. In connection with this he is entitled for on duty leave during the mentioned period.

Dean-Research
Prof. (Dr.) R.B Jadeja
Marwadi University
Rajkot

Copy to:

1. Deans and Principals of University
2. Head - HR
3. Concern File

MARWADI UNIVERSITY * RAJKOT *

IMO-IMOMEC

UHASSELT imec

Diepenbeek, 20th of October 2021

Content: Recommendation letter dr. Prashant Ghediya, Marwadi University, India

Dear Sir, Miss,
To whom it may concern,

Dr. Prashant Ghediya, a postdoc visitor, performed a 3-month research stay within my research from August until October 2021. During his stay in Belgium, he showed his research and management skills to perfectly conduct and management a research project on the ink formulation and ultrasonic spray coating of CZTSSe solar cells with the aim to apply these cells within tandem solar cells, a research scope within our research group and with Prof. Bart Vermang, Energyville.

Prashant has a vast knowledge in the development of inkjet printing and drop casting of CZTSSe solar cells from his home university and earlier research internships and learned in this research stay how to adapt these inks for a large area, thin film coating technology, ultrasonic spray coating. Prashant is a very hard-working researcher with a clear focus in mind, giving all he can to achieve his goals. He works very structured and complete, which resulted in a fully characterized work that is ready to be published in a high impact journal.

Further, Prashant is a very good communicator and was able to interact not only with the research colleague he was performing research with but also with other colleagues in an informal atmosphere, perfectly mixing in the research group and research environment at Hasselt University.

Finally, I would like to point to the management skills of Prashant. As indicated above, he has excellent research skills and works very structured and complete and is an enthusiastic and social person. In view of a project in which his task is part of a bigger storyline (printing of tandem solar cells), he captures the full story, knows what is his part of the project and how and what he should deliver for other people to proceed with their work.

With this, I would like to enphasize that the research, management and personal skills of Prashant make him a valuable researcher in any research environment and absolutely an added value for your research team.

Sincerely yours,

Prof. dr. ir. Wim Deferme

Associate Professor
Hasselt University
Faculty of Engineering Technology
Imo-Imomec - Functional Materials Engineering
T +32(0)11 26 88 74 - F +32(0)11 26 88 99
E wim.deferme@uhasselt.be


VISA
BELGIË/BELGIQUE/BELGIUM
BEL
050027611
BELGIQUE
01-08-2021
31-10-2021
91
D
R1637199
MULT
MUMBAI
08-07-21
GHEDIYA PRASHANT RAMNIKLAL
BNL 2
B13
050027611
VDBELGHEDIYA<<PRASHANT<RAMNIKLAL<<<<
050027611 4IND8509152M2110318<M<<0801

GUEST AGREEMENT

In view of the permission for a stay of more than 3 months in Belgium of a foreigner from outside the European Union, invited as a researcher by a recognized research institute to carry out a research project,

In view of the European Guideline 2005/71, concerning a specific procedure for an admission of citizens from third countries, aiming at scientific research,

In view of the law of 15 december 1980 concerning entrance to the territory, the stay, the residence and the dismission of foreigners,

In view of the Royal Decree, concerning the conditions for recognition of research institutes

The institute mentioned below:

Name : Universiteit Hasselt
Company number: 208 359 859
Address : Martelarenlaan 42 – 3500 Hasselt

Head of the insititute :
Name: Prof. Dr. Bernard Vanheusden
Position (rector, director, president, etc.) : Rector

declares it will host, as a researcher:

Name (Mr.) : Ghediya
First Name : Prashant R.
Date of birth : September 15, 1985 Place of birth : Mithapur Dwarka, Gujarat
Nationality : Indian
Current residence :402/Capital gold, Near alap green city, Raiya main road, Rajkot-360007, Gujarat, India
Passport number : R1637199
Position : Assistant professor
Diploma : PhD Physics
Employing, or visited, institution of Higher Education (before the stay in Belgium): Marwadi University, India

For the following project :

Title of the research project:Development of functional inks for ultrasonic spray coated new emerging materials for tandem solar cells
Projectleader (promotor) : Prof. dr. ir. Wim Deferme
Location : Universiteit Hasselt - Building H, Wetenschapspark 1- B-3590 Diepenbeek

According to the following hosting regulation:

Kind of juridical relation: Visiting Researcher
Monthly Income (bruto) : 1.650 euro
Type of income: ☐salary ☐scholarship ☒ other (give detail) : BOF 2021 - Incoming Mobility - BOF21KV05 (Daily allowance)
Institute who finances the researcher: Universiteit Hasselt
Duration : from August 1st, 2021 till October 28th, 2021.

And declares that the person mentioned above has enough means at his disposal to cover all accomodation expenses, as well as social costs, and to pay for his return to the home country.

Done in duplicate in Hasselt, on 12/05/2021

For approval,

Prof.dr. Bernard Vanheusden, rector UHasselt

Signature of the Head of the institution. Signature of the researcher

Progress report on research work done at IMO-IMOMEC, Hasselt University, Belgium

by

Dr. Prashant R. Ghediya
Assistant professor
Department of Physics
Marwadi University

Title: Ultrasonic spray-coating of Cu-based new emerging materials for tandem devices

Under the guidance/supervision of

Host: Associate Professor Wim Deferme, Hasselt University, Belgium

Submitted to:

The Dean-Research, Professor R. B. Jadeja, Marwadi University, Rajkot

Duration: 01 August to 30 October 2021

Introduction

Dr. Prashant Ghediya from Marwadi University, Rajkot has been invited as a postdoc visitor to oversaw the research activity of IMO-IMOMEC and to carry out the joint research project entitled 'USSC of new emerging materials for tandem devices' by Hasselt University, Belgium for 3 months (August to October 2021) under the superstition of Associate Professor Wim Deferme. This report briefs the research work done during the stated period along with the outcome of this visit and benefits to both the organisation. The report divided into following three main categories:

1. Research work done

2. Presentation and collaboration

3. Outcome and further plan

Research work done:

This section is divided into the three section according to month August to October 2021. In the first month, Cu-based quaternary new materials such as CZTS, CCoTS, CFTS, CNTS, and lately CCdTS. Ink of each materials has been developed for the deposition of ultrasonic spray-coating (USSC) and dip-coating for solar PV. USSC will provide thicker films (5-10 µm) and dip-coating will give thin films (200 to 600 nm). Films has been then developed as seen in Fig. 1 after heat treatment in atmospheric condition.

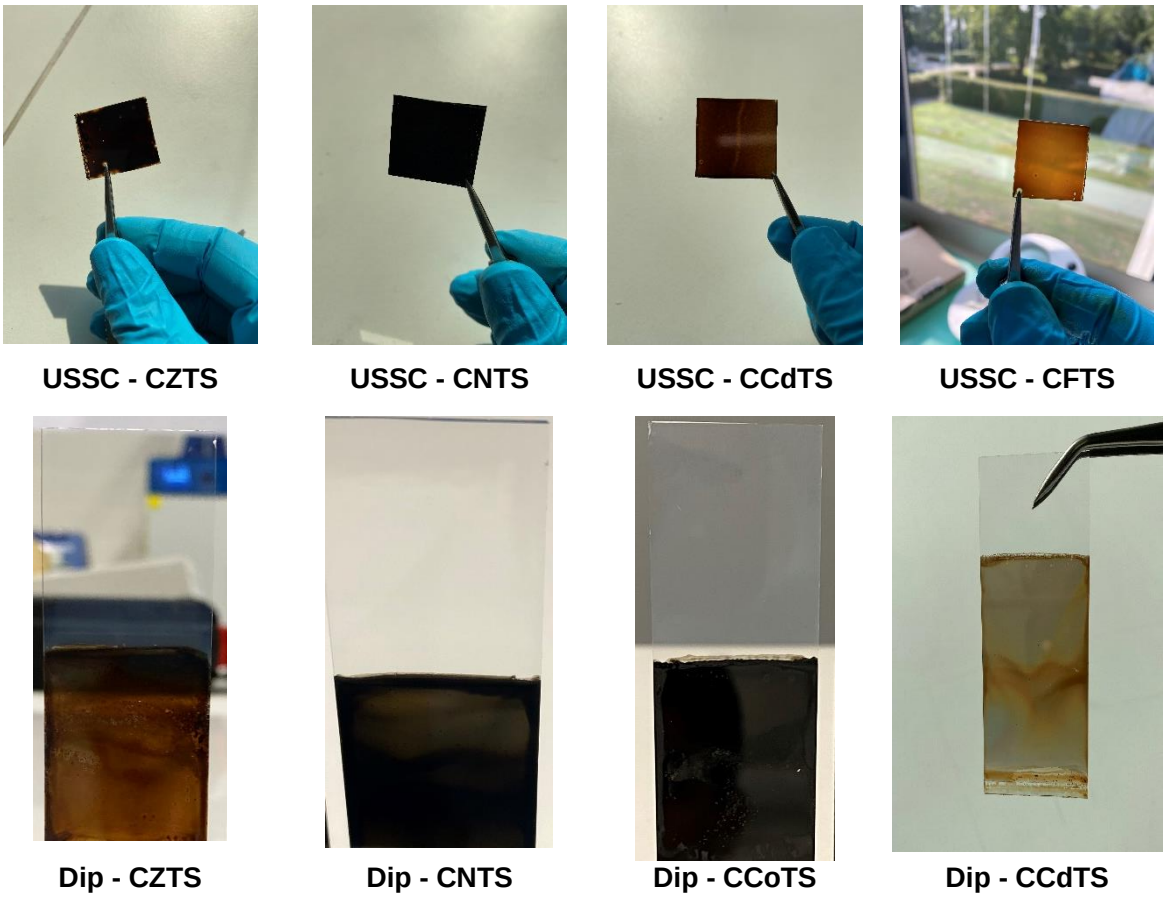


Fig. 1 Image of USSC and dip-coated Cu-based new emerging materials

In the second month, some preliminary characterisation such as, contact angel (CA) measurement, kelvin probe force microscopy/Atomic force microscopy (KPFM/AFM) has been done to check the adhesion as well as morphological properties. Fig. 2 displays the CA measurement of all types of films. It can be seen that CA of each films is less than 90º which suggest that films are hydrophilic.

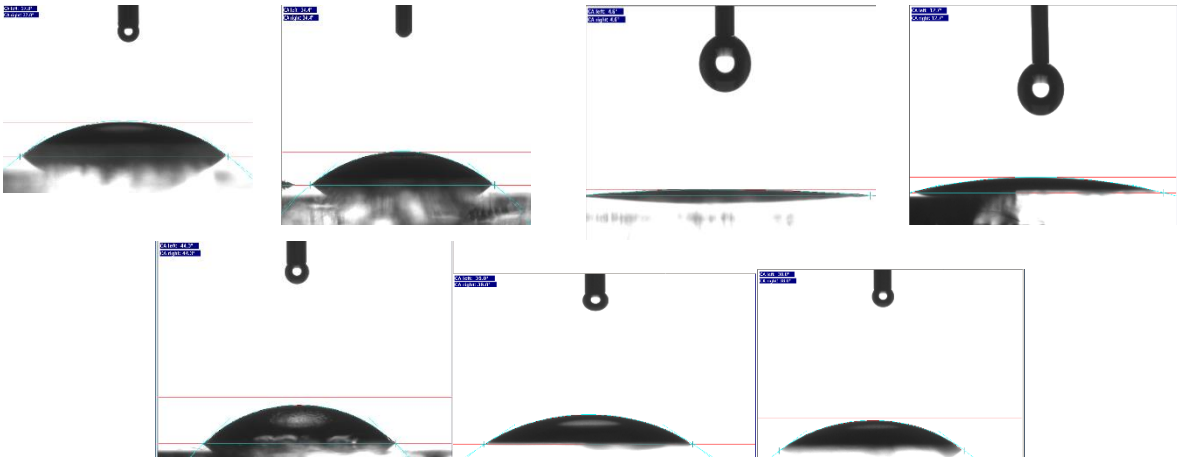


Fig. 2 Contact angel measurement of USSC and dip-coated films.

Figure 3 and 4, respectively shows the AFM of USSC and Dip-coated films. In general, the films are rough. Both 2D and 3D view of films are displayed in the fig.

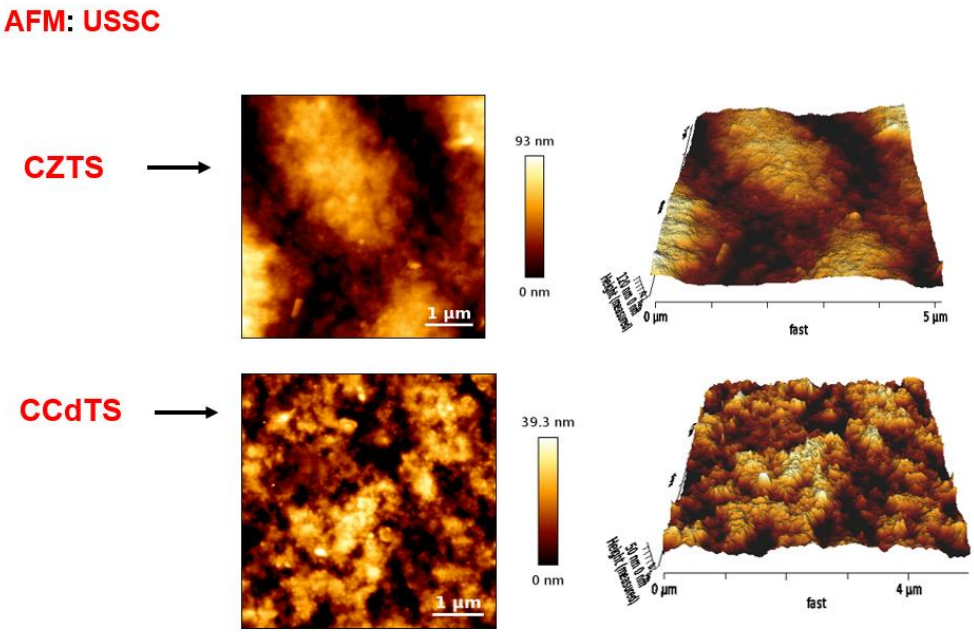


Fig. 3 Atomic force microscopy of USSC and films.

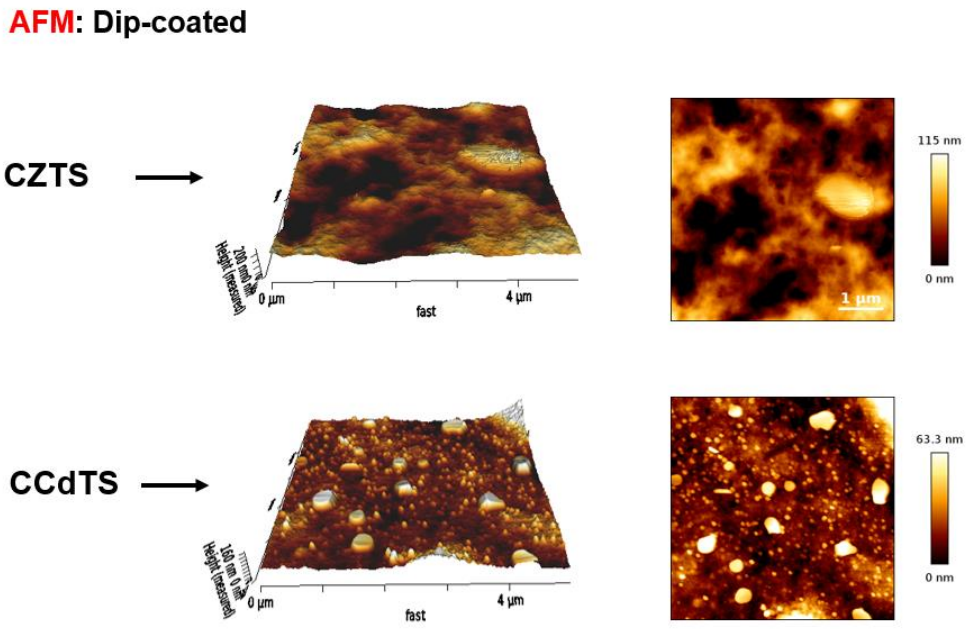


Fig. 3 Atomic force microscopy of Dip-coated films.

Both rms and average roughness of dip and USSC coated CZTS and CCdTS films are tabularised in Table 1. Dip-coated films are smoother and homogeneous than USSC.

Table 1 RMS Roughness (nm) and average roughness calculated from AFM

Sample	RMS roughness (nm)	Average roughness (nm)
USSC CZTS	21.15	17.65
USSC CCdTS	8.9	7.2
Dip CZTS	26.06	20.14
Dip CCdTS	14.3	9.8

Films are characterised for their structural and optical analysis. Optical properties of both type of films are studied in detail. Absorption and transmittance of both type of films are depicted in Fig. 4 and 5, respectively. USSC films shows more than 80 % transmittance while dip coated ones show almost 70 % in the IR region. Transmittance of all type of films decreases with decreasing wavelength reveals the semiconductor nature of the films. Sharp absorption edge appears at around 800 to 900 nm due to CZTS/CCdTS. The result shows that these materials can be used as an absorber for thin film solar cells. However, details characterisation is required to double check the optical properties. Following section provides the detail optical properties such as, extinction coefficient, refractive index, absorption coefficient.

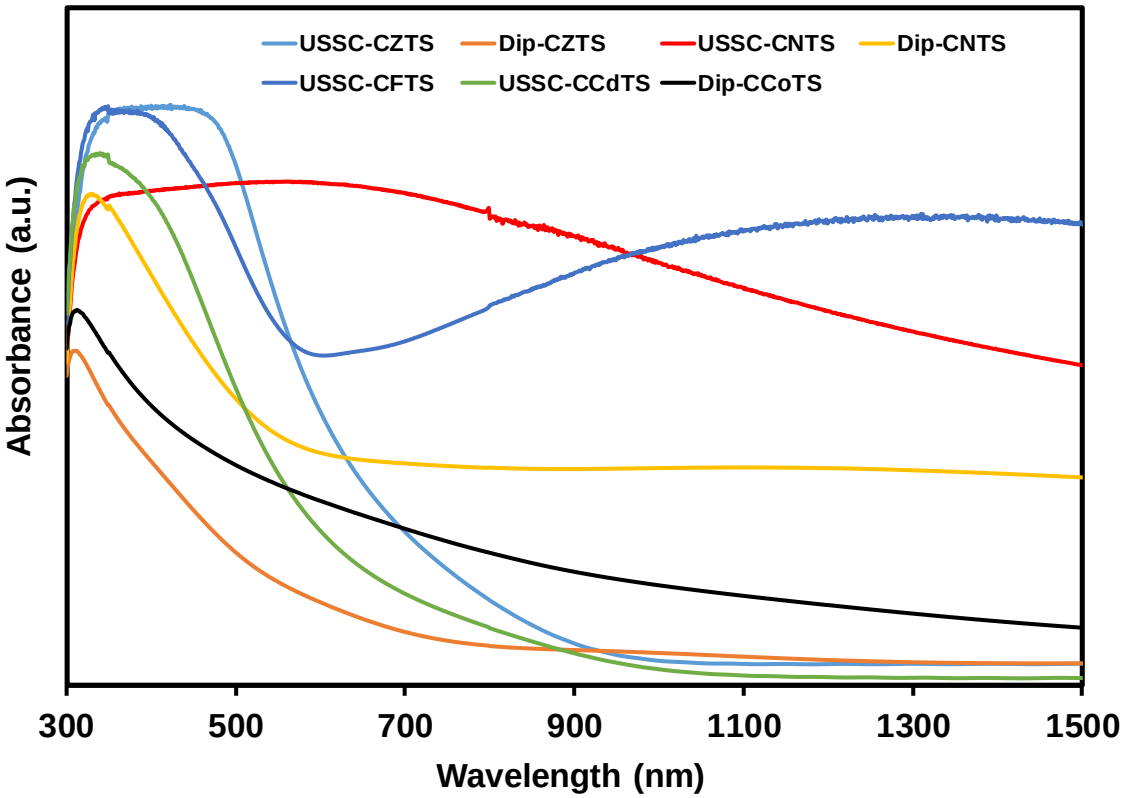


Fig. 4 Fig. 5 Absorption spectra of Cu-based quaternary semiconductor films.

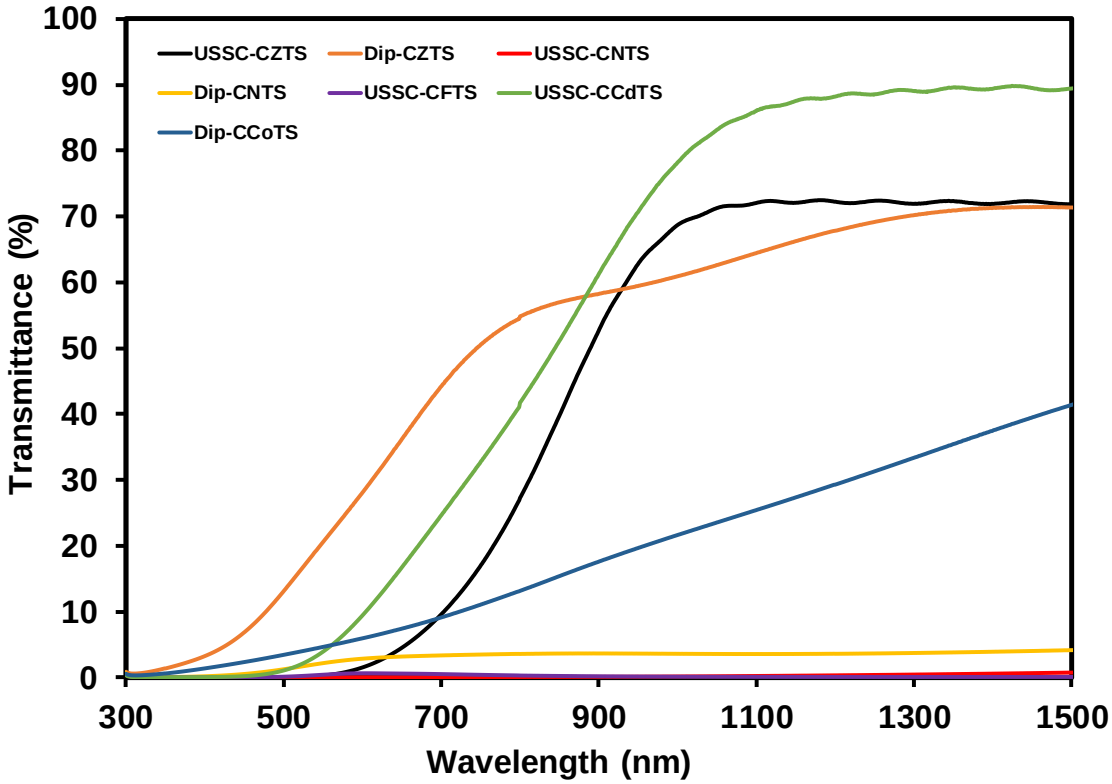


Fig. 5 Transmittance of Cu-based quaternary semiconductor films.

Band gaps of the films have been estimated from the well-known Tauc relation as described in Fig. 6. Analysis of the data reveals that all the films shows direct transition with band gaps of 1.2 to 1.6 eV.

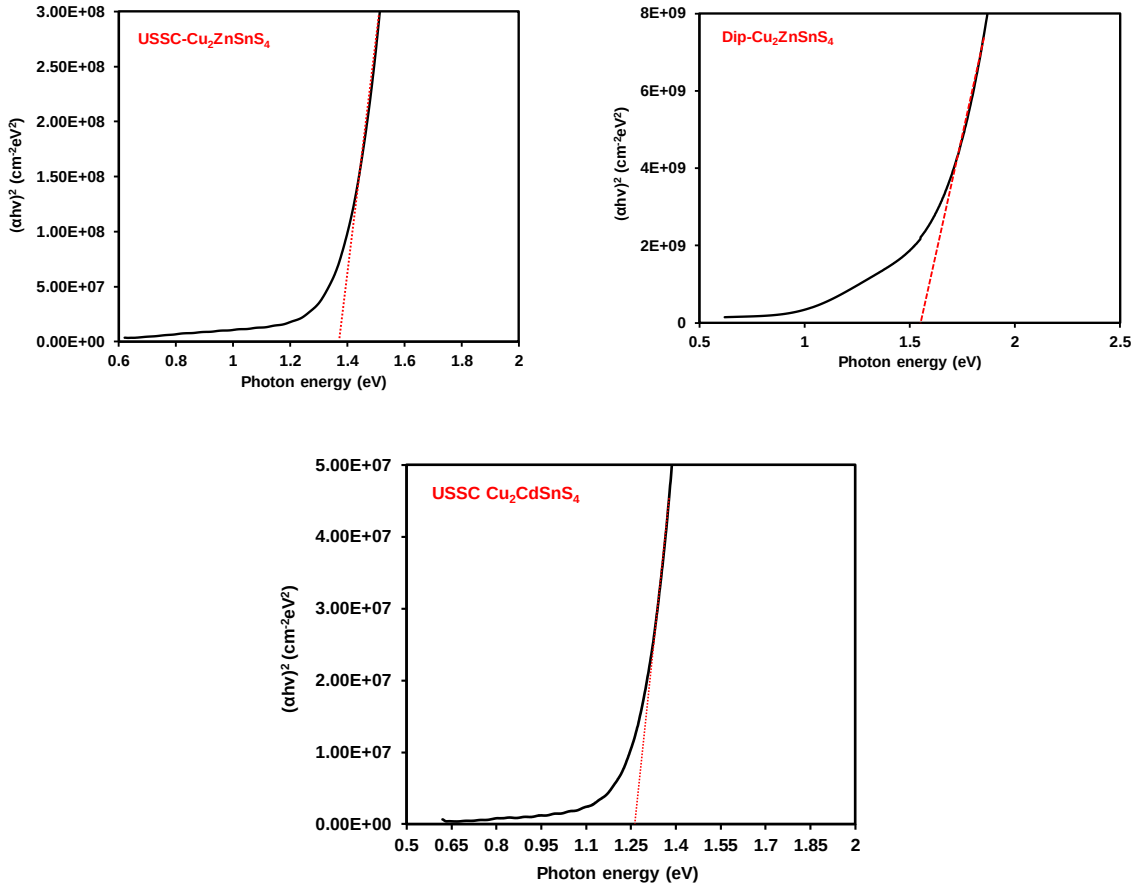


Fig. 7 Band gap calculated using Tauc relation.

Figure 8 shows the transmittance and reflectance of USSC CZTS films in the wavelength range from 400 to 1400 nm.

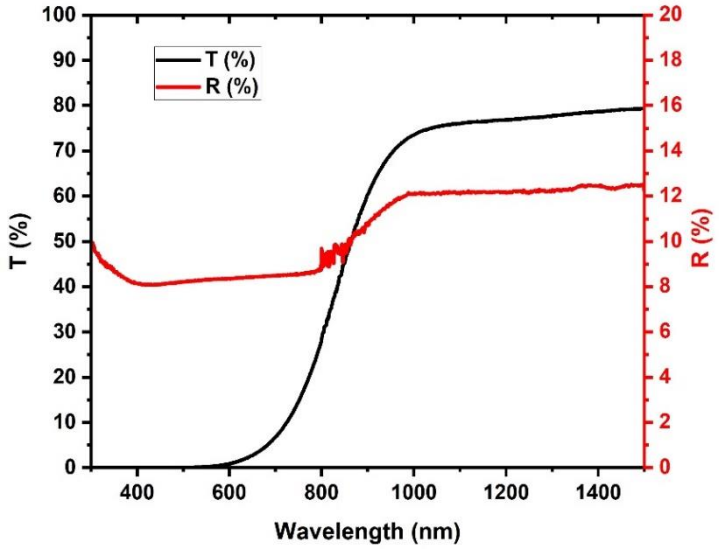


Fig. 8 Transmittance and reflectance of USSC CZTS films.

Figure 9 Band gap, absorption coefficient, extinction coefficient and refractive index calculation of USSC CZTS films from transmittance and reflectance spectra. The value has been found identical with literature.

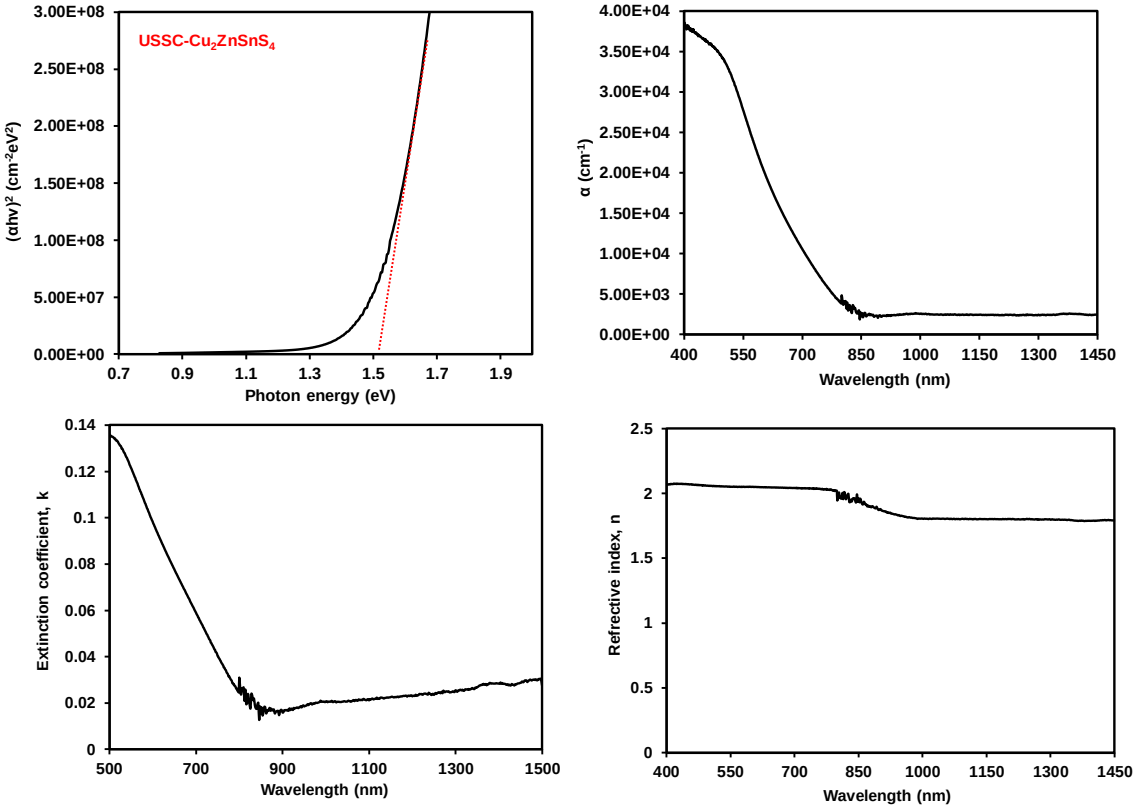


Fig. 9 Band gap, absorption coefficient, extinction coefficient and refractive index of of USSC CZTS films.

Figure 10 shows the transmittance and reflectance of USSC CCdTS films in the wavelength range from 400 to 1400 nm.

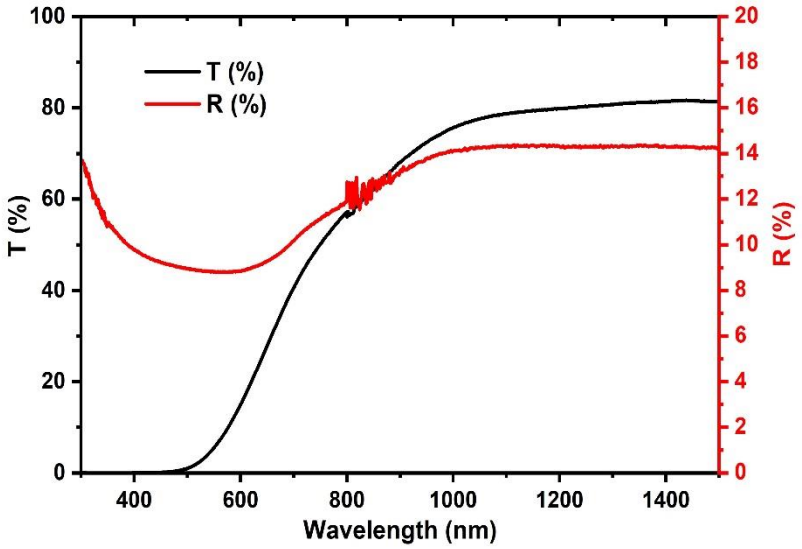


Fig. 10 Transmittance and reflectance of USSC CCdTS films.

Figure 11 Band gap, absorption coefficient, extinction coefficient and refractive index calculation of USSC CCdTS films from transmittance and reflectance spectra. The value has been found identical with literature.

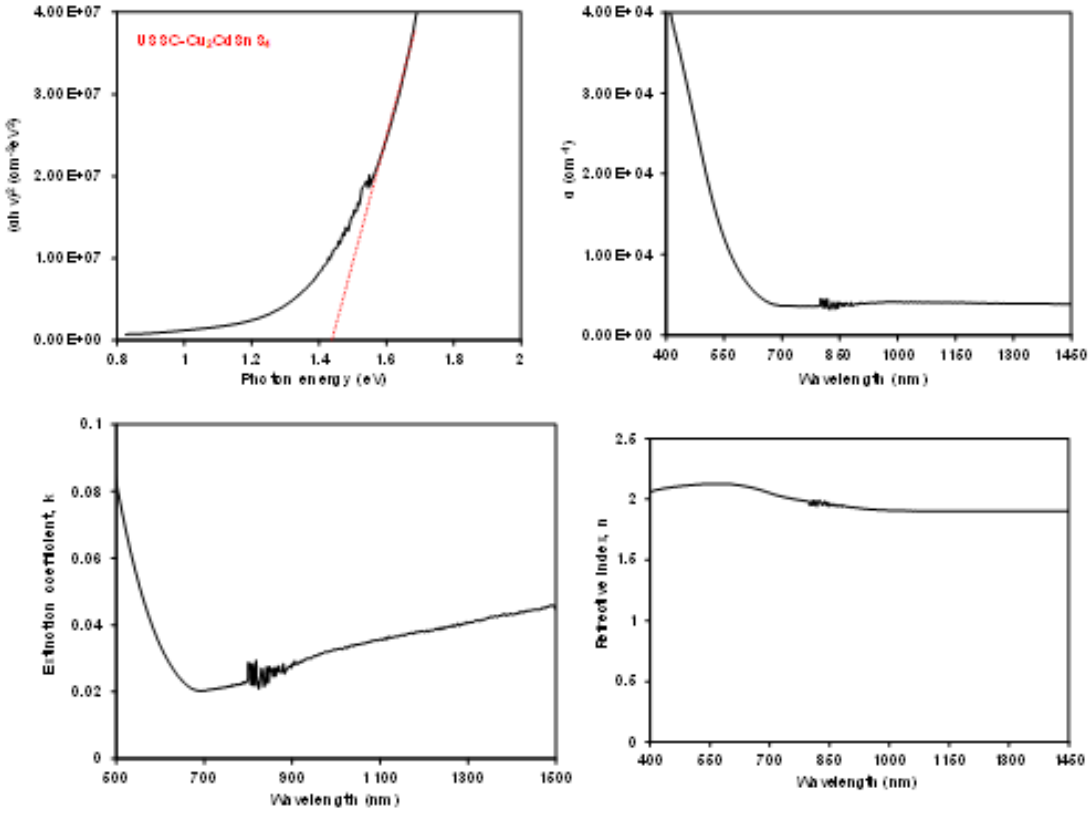


Fig. 11 Band gap, absorption coefficient, extinction coefficient and refractive index of USSC CCdTS films.

Figure 12 shows the transmittance and reflectance of dip-coated CCdTS films in the wavelength range from 400 to 1400 nm.

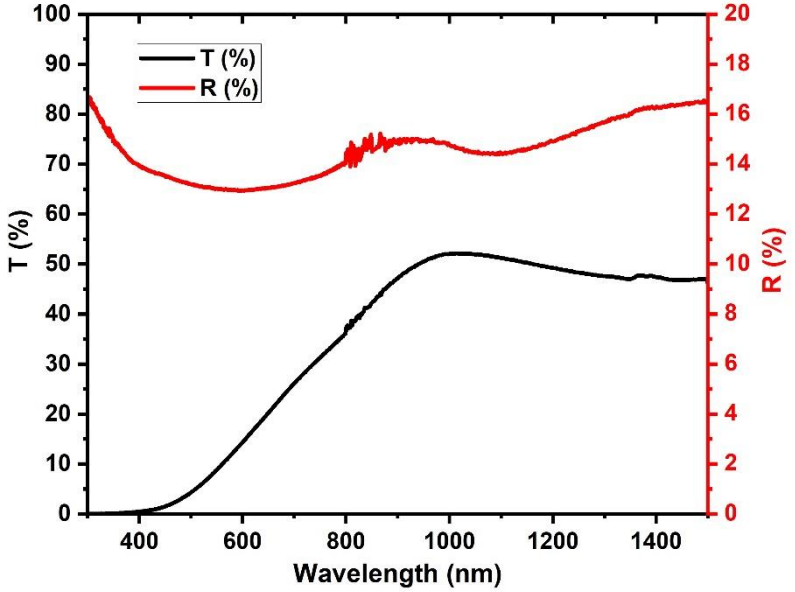


Fig. 12 Transmittance and reflectance of dip-coated CCdTS films.

Figure 13 Band gap, absorption coefficient, extinction coefficient and refractive index calculation of dip-coated CCdTS films from transmittance and reflectance spectra. The value has been found identical with literature.

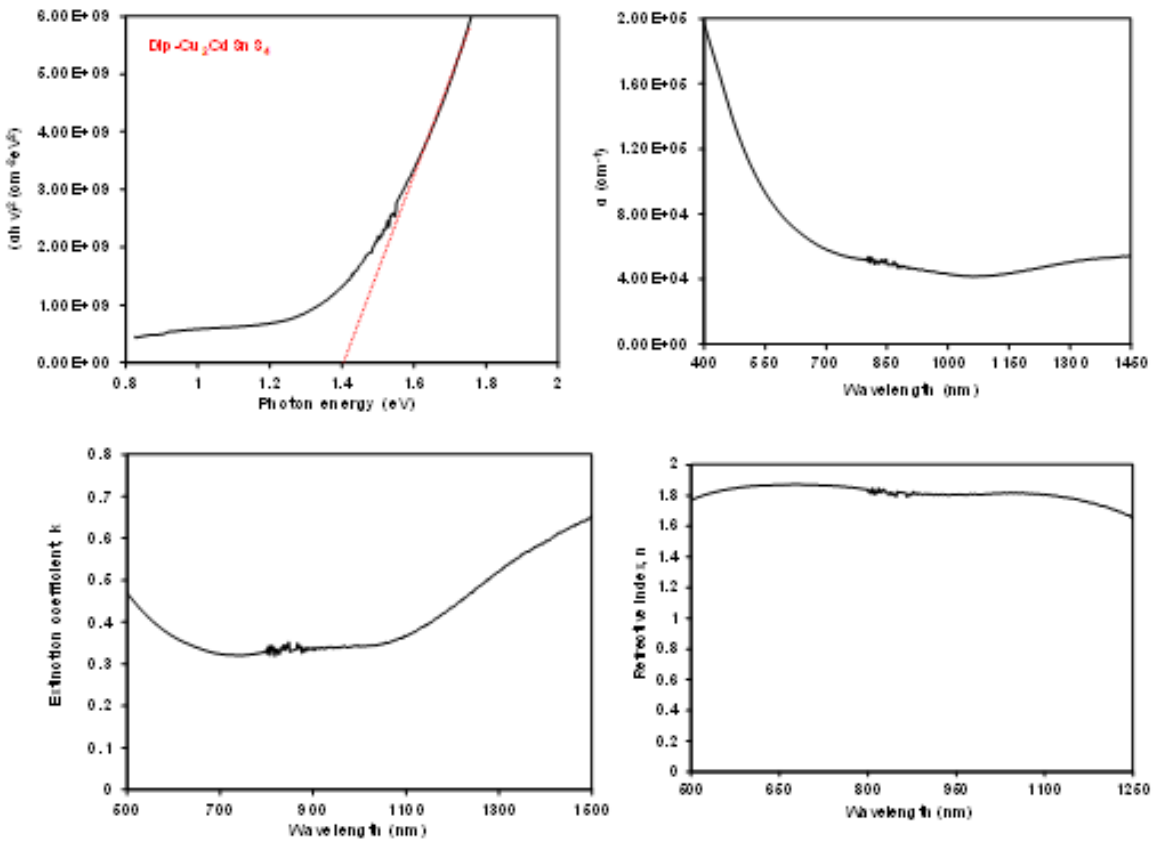


Fig. 13 Band gap, absorption coefficient, extinction coefficient and refractive index of dip-coated CCdTS films.

Table 2 shows the estimated optical parameters of both USSC and dip-coated CZTS and CCdTS films. It can be seen that for each films, absorption coefficient has been found as 10^4 cm^{-1} while refractive index is found to be around 2.

Table 2 Optical parameters of USSC and dip-coated CZTS and CCdTS films.

Material	Transmittance (%)	Eg (eV)	α (cm^{-1})	k	n
USSC CZTS	80	1.5	10^4	0.02	1.97
Dip CZTS	70	1.6	10^4	-	-
USSC CCdTS	80	1.42	10^4	0.03	1.95
Dip CCdTS	50	1.4	10^4	0.35	1.8

In the last month, some more characterisation such as, x-ray diffraction, Raman spectroscopy, SEM, EDX of USSC and dip-coated samples have been performed.

Since dip-coated films are too thin, x-ray diffraction of only USSC CZTS and CCdTS films are measured as shown in Fig. 14. All the 2theta peaks are matching with the standard JCPDS file reveals formation of pure kesterite phase.

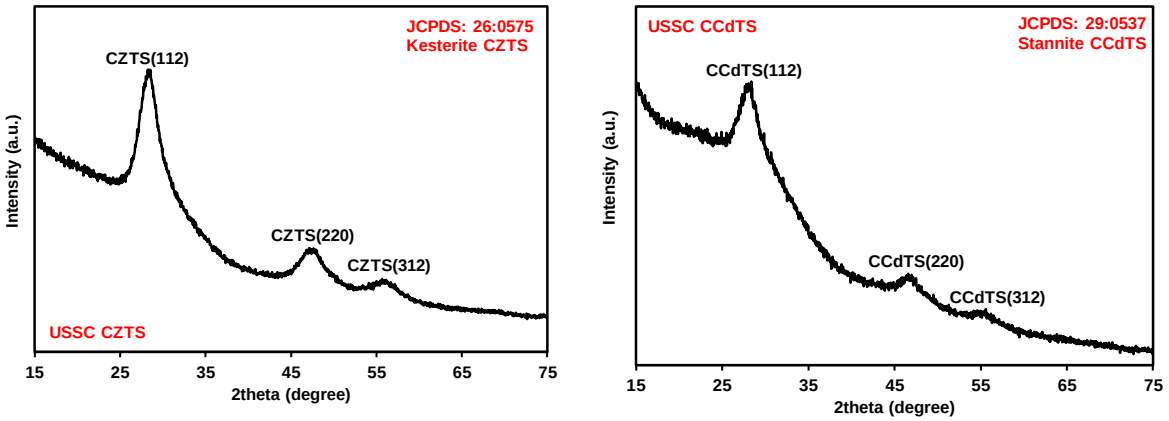


Fig. 14 X-ray diffraction of USSC CZTS and CCdTS films.

Figure 15 displays the Raman spectroscopy of USSC and dip-coated CZTS and CCdTS films. In case of, only peak at 330 cm^{-1} appears while in case of CCdTS, two peaks appear: 300 and 330 cm^{-1}. These peaks are due to the pure CZTS and CCdTS.

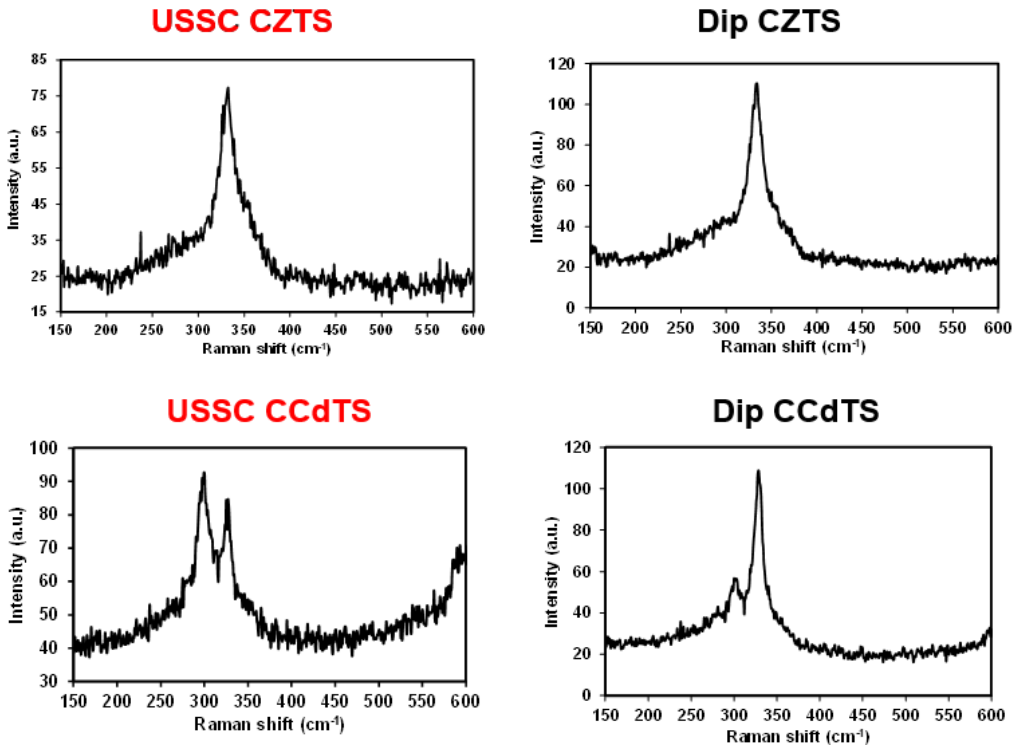


Fig. 15 Raman spectroscopy of USSC and dip-coated CZTS and CCdTS films.

Figure 16 displays the scanning electron microscopy (SEM) images of USSC CZTS and CCdTS films. All the films are smooth and homogeneous. There is no porosity, holes or cracks has been found throughout the samples.

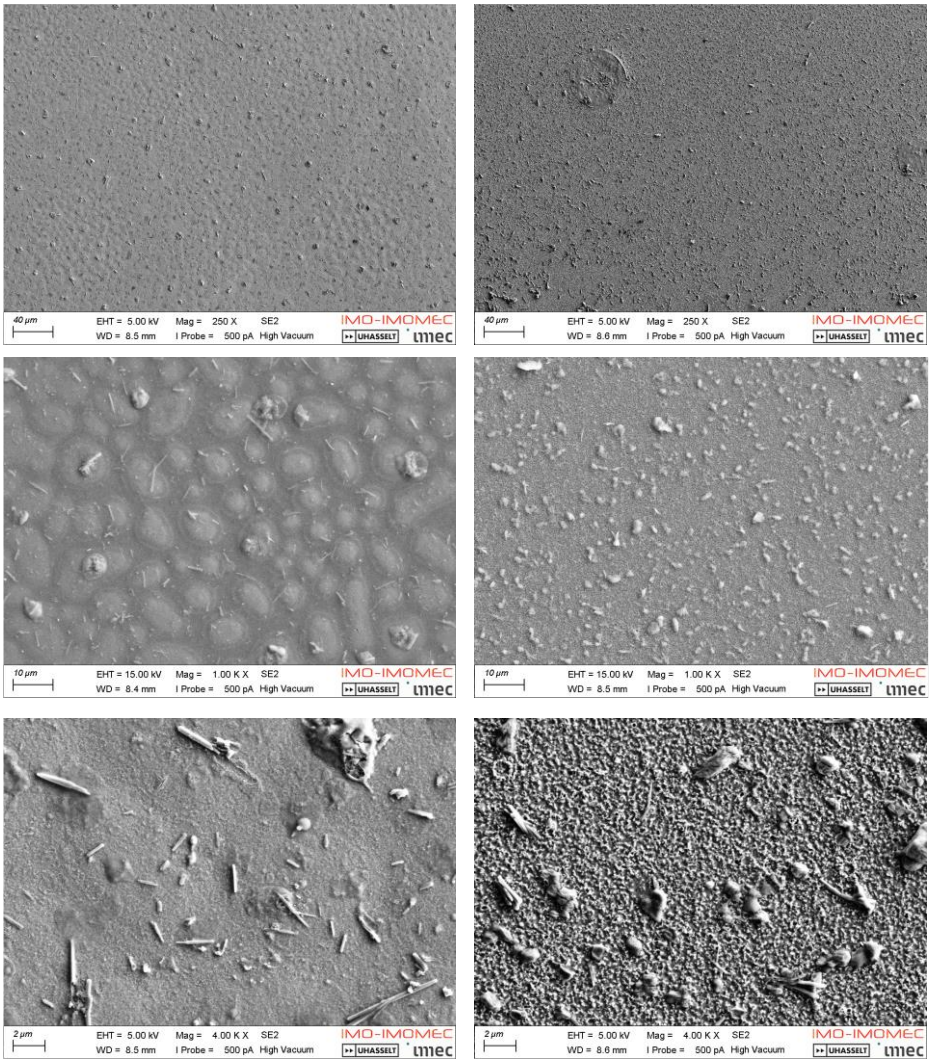


Fig. 16 SEM images of USSC CZTS and CCdTS films.

Figure 17 and 18, respectively describe the EDX spectrum of USSC and dip-coated CZTS and CCdTS films. Only peaks due to chemical elements such as Cu, Zn, Cd, Sn and S has been observed. Peak due to Cl has been found in USSC samples while major peak due to Si has been found in case of dip-coated samples.

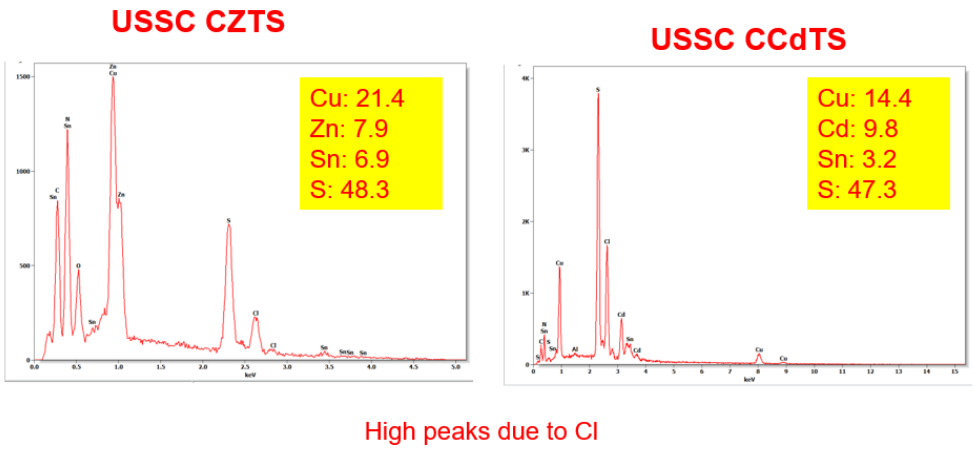
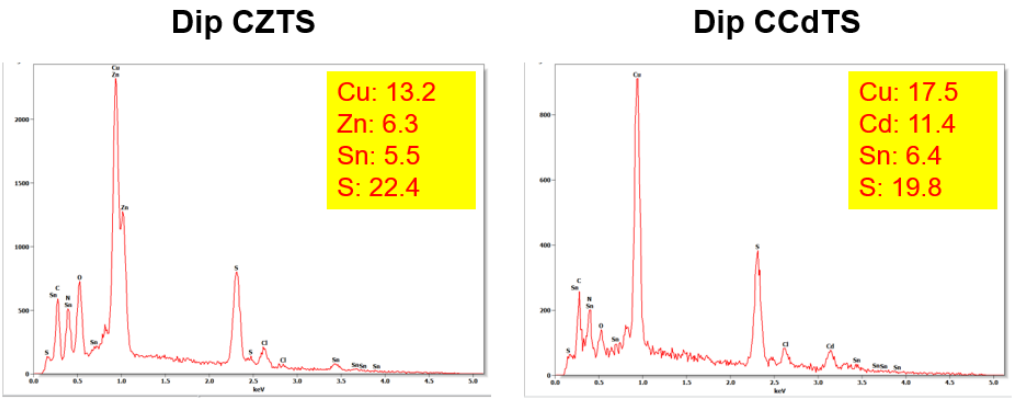


Fig. 17 EDX images of USSC CZTS and CCdTS films.



High peaks due to Si, Cl, Ca

Fig. 18 EDX images of dip-coated CZTS and CCdTS films.

Presentation and collaboration

The progress of the work has been presented in monthly meeting (Aug, Sep and Oct) with group members leaded by Prof. Wim Deferme. Also the work has been presented at mini symposium on organic electronics at Winterberg, Germany on 07 Sep 2021. The symposium was organised by chemistry department leaded by Prof. Koen Vandewal. The title of talk was: Ink-processed emerging materials for thin film solar cells. During this visit, Dr. Ghediya has collaborated with many researchers at UHasselt. However, the main considerable collaboration is with partner institute of UHasselt, i.e. EnergyVille (EV). EV is well-known for the fabrication of Kesterite based CZTS solar cells. The leader of the group is Prof. Bart Vermang. I have learned the fabrication and Physics of solar cells including, CBD process for n-type CdS which forms the junction with absorber layer.

Outcome (measurable) and futuristic plan

Performing research at IMO-IMOMEC, UHasselt, Belgium have created / will create many opportunities and benefits to our University. Here are some the specified outcomes:

- Expecting joint research paper in high impact journals with MU affiliation
- Performing advanced characterisation tools such as Photoluminescence (PL) spectroscopy, cyclic voltammetry (C-V) measurement will definitely help not only to me but also to our faculty members as well as our students to write excellent scientific proposals for funding
- Collaborated with field expert specially Prof. Bart and Vermang and Dr. Sudhanshu Shukla will provide new identity to the funding agencies
- Learned the art of technical writing (specially project writing)
- The performing research at UHasselt have provided the new opportunity and freedom to build a strong research group at Department of Physics, MU
- On the top of all, students of Department of Physics, MU will be benefited by this visit in terms of executing final year project dissertation with aim to pursue higher education (Ph.D.) in one of the most emerging fields of science and technology specially materials science for solar PV.