

# How to Write a Proposal

The same as any other scientific report

(Well, almost)

## **Purpose of proposal**

Respond to RFP or RFQ

Solicit support

From granting agency

From potential client

Convince someone to part with money

And to give it to *you*

In this case, convince adviser to let you continue

## **Format of proposal**

Report format (with cover letter or cover memo), or

Short or informal proposal

Letter (external) or memo (internal)

## Style of proposal

Same as technical report or paper, but

Written partly in future tense

Using *will* not *would*

Write to *inform* uninformed reader, and

*Convince* informed reader that you know your stuff

See also *GWE*, first (1997) ed., pp. 109-114

# Sections of proposal

*Cover sheet* or title page – don't bother

## *Introduction*

Clear statement of problem to be solved

Specifications

Constraints

Background (*after* problem statement)

Evolution of the problem

Why the problem is interesting

How it fits into larger framework

## *Body of proposal*

Progress report (if applicable)

What you have done so far

How you will solve the problem

Solutions you considered and rejected (if applicable)

*Statement of work* (additional section besides those in a normal scientific report)

What you will do

When you will do it (timeline)

*Facilities, Equipment, and Other Resources* (available for project) – if appropriate and very brief

*Cost analysis* – you must have one

Assume no labor costs, up to \$1000 for supplies

*References*

Cited in text and numbered in order of citation

Required

Typically, 3-6 *technical* references

Pls use AIP format

*Biographical Sketches* – don't bother

Christie Garner graciously allowed us to post a proposal that she submitted to the Materials Research Society in 1999. It received honorable mention. Here it is as a sample. Note the depth of research that went into preparing this proposal. The summary and the introduction might have been improved if they began with a problem statement such as the first sentence in the second paragraph of the summary. The statement of work is here called "Technical Project," evidently in accordance with the instructions of the Materials Research Society.

#### UMRI COVER SHEET

Materials Research Society - Undergraduate Materials Research Initiative (UMRI)

Topic Keyword Code (see Table in Section III): III.A.4

Date: October 13, 1999

Title of Proposed Project: Properties of polycrystalline ZnTe ion-implanted with N:  
Applications for Photovoltaic Cell Back Contact

Requested Amount: \$750 + \$250 student award

Name and Address (including phone and email) of Undergraduate Student Investigator:

Christie Garner

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Phone (303)-xxx email: xxx

Name and Address (including title, phone and email) of Advisor supervising research:

Dr. Uwe Greife, Assistant Professor

Department of Physics

Dr. Tim R. Ohno, Associate Professor

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Name and Address of Institution:

Department of Physics  
Colorado School of Mines  
Golden, CO 80401

Signature of Investigator: \_\_\_\_\_

Signature of Advisors: \_\_\_\_\_

[\* Note to Advisor: you are committing to the seeing this project through to completion (culminating in a final report with a strict due date of March 31, 2000) if you sign here]

Authorized Institutional Grants Administrator:

\_\_\_\_\_ (sign)

\_\_\_\_\_ (print)

## Section A

### Project Summary

Photovoltaics hold the promise of providing part of our future energy needs as fossil fuel supplies dwindle. The cost of solar cells can be decreased by the use of thin film technologies. One material that has near optimum properties for an absorber layer is CdTe. Cell efficiencies as high as 15.8 % have been reported for small cells. However the use of copper as a dopant in all contact layers to high efficiency cells has been identified as a contributing factor in degradation of properties with time. This currently is a limiting factor in the production of a commercially viable product.

The research objectives of this proposed study are to determine the electrical, optical and physical properties of ZnTe ion-implanted with nitrogen. Nitrogen is known to heavily dope ZnTe p-type if the atom can be incorporated at a high concentration. For the  $^{14}\text{N}$  implantation, this project will use the 180 kV accelerator of the Colorado School of Mines which was used previously only in nuclear physics experiments. It will be part of this project to implement an implantation set-up at its beam line. Electrical properties will be measured with a Hall measurement system. Sample morphology and composition will be determined with atomic force microscopy and x-ray photoemission spectroscopy. The effects of implantation profile and concentration, as well as post-annealing will be examined to optimize the highly-doped semiconductor for application as a back contact on a CdTe/CdS heterojunction solar cell. The results of this study may demonstrate the feasibility of using an alternative acceptor for creating an ohmic contact that is stable.

## Section B

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## Section C

### Project Description

#### Introduction

Commercial uses of solar cells have been dominated by silicon, largely a result of advances made by the semiconductor and space industries. However, as a clean alternative energy source for widespread use the cost of the system must be reduced. Thin film photovoltaics, primarily amorphous silicon, copper-indium-gallium-diselenide (CIGS), and cadmium telluride (CdTe), may provide this option. The combination of low cost deposition techniques and reasonable high efficiencies result in a competitive technology. For small cells CIGS has shown a record efficiency of 18.8 %, while CdTe has a record small cell efficiency of 15.8 %. There are currently two companies in the United States producing CdTe modules, BP Solar in Fairfield, CA, and First Solar in Toledo, OH. One remaining barrier to widespread commercialization is module lifetime. Both modules and small cells show some loss in efficiency over time. The cause and remedy of this degradation is the focus of this project.

N-type CdS/p-type CdTe solar cells are widely used to form the diode required for efficient collection of current generated by absorption of photons (Fig. 1). The energy gap of CdTe (1.5 eV) has an optimum value for absorption of our terrestrial solar spectrum, with the CdS serving as a window layer. The front contact, which allows light through to the diode, is typically highly conductive and transparent SnO<sub>2</sub>. The back contact has proven to be the layer of most difficulty. There are no metals that form an ohmic contact with p-type CdTe. The Schottky contact that is formed when a metal is deposited has a high contact resistance, resulting in serious loss of efficiency. One solution is to make the Schottky barrier sufficiently thin that carriers may tunnel through, producing a low effective resistance. This is typically done by highly doping the CdTe near the surface or by adding a highly doped p-type layer atop the CdTe before contacting with a metal. A common element of all contacts is the presence of copper.

Figure 1. Schematic of CdS/CdTe solar cell

Cu is known to act as an acceptor when Cu atoms occupy a cation site such as Cd in CdTe. Moreover very high doping densities have been obtained with Cu-doped ZnTe, and several groups have investigated this as an intermediate layer [1-3]. Cu has also been linked to degradation of the solar cells. Under stresses, either temperature, load or illumination, Cu-containing contacted cells show a

decrease of efficiency that has been attributed to movement of Cu into the vicinity of the CdS/CdTe junction [4]. As a result alternative contacts that provide the high efficiencies of Cu-containing contacts have been investigated.

## Technical Project

Investigations into high p-doping of compounds such as ZnTe and ZnSe have focused on the MBE grown structures used for blue LEDs and injection lasers. The difficulty in incorporating large amount of dopants in these materials has been attributed to the poor sticking coefficients during growth. Nitrogen in particular suffers from low reactivity of the common gas phase precursors, N<sub>2</sub> and NH<sub>3</sub>. One successful method of producing high N concentrations is deposition of ZnTe in the presence of a N plasma [5]. Hall measurements show an optimum carrier concentration of  $9 \times 10^{18} /\text{cm}^3$  and a mobility of 50 cm<sup>2</sup>/(V·s) for samples prepared at 275 – 400 °C. This is greater than has been reported for Cu-doped polycrystalline ZnTe thin films [1,2]. However attempts at heavy p-doping of polycrystalline ZnTe by introduction of N<sub>2</sub> with Ar in an RF sputter deposition system were unsuccessful [3]. The resulting films showed resistivity 2000 Ω/square greater than Cu-doped material, suggesting the excited N species in the plasma did not incorporate in the growing film.

A novel alternative way of introducing nitrogen would be ion-implantation into a thermally evaporated ZnTe layer. The <sup>14</sup>N implantation will be performed at the 180 kV accelerator of the Colorado School of Mines. As this machine was used in the past only for low energy nuclear physics experiments, one of the first tasks of this project will be to implement an implantation setup at its beam line. A vacuum chamber providing a suitable vacuum in the 10<sup>-7</sup> Torr range is existing. It will be equipped with an aperture system and target holder defining the implantation area and allowing an accurate determination of the implantation dose at low implantation currents of the order of 1 nA. The simulation of the implantation with the SRIM code [6] shows that for the given layer structure an implantation energy of 27 keV provides the best centering of the distribution in the ZnTe layer (Fig. 2). In order to ensure a uniform lateral distribution the beam will be scanned over the target by varying the current through the existing beam steering electromagnets. An implantation over the area of 3 x 3 mm<sup>2</sup> will require about 10<sup>13</sup> implanted <sup>14</sup>N (already corrected for recoil losses) to reach a concentration of 10<sup>19</sup> N atoms/cm<sup>3</sup>. In order to allow heat dissipation in the target the implantation current will be limited to 10 nA corresponding to a power deposition of 0.3 mW in the 100 nm thick ZnTe layer. The necessary time for one implantation should thus be only 160 s.

Since N must be in a Te site and the material must be crystalline, post-annealing will be studied to investigate changes in electrical properties. The ion-induced disorder and the low formation energy for N in a Te site (calculate to be ~0.27 eV in Ref. 7) suggest that film properties would improve. The range studied will be limited to less than 400 °C, the maximum annealing temperature for the CdS/CdTe cell. For Cu-doped samples annealing at temperatures greater than 200 °C results in improved conductivity and grain growth [2].

Figure 2. Depth profile of the implanted  $^{14}\text{N}$  ions.

### Characterization

The Center for Solar and Electronic Materials at the Colorado School of Mines provides a wide range of materials characterization techniques. Given the resources of this project we will focus on electrical and structural characterization, with some optical and chemical composition analysis for the best samples. More specialized characterization will be performed by the existing CdTe research group.

The formation of a good ohmic contact is primarily based on sufficiently high doping and high mobility. The results for MBE ZnTe are promising, but the same measurements must be repeated on the ion-implanted polycrystalline samples. For optimization studies thin layers grown on either glass slides or sapphire substrates will be patterned with gold contacts in the van der Pauw geometry. The BioRad HL5500PC Hall measurement system has a uniform 0.32 T field over a radius of ~12 mm and easily accommodates typical samples of area 3 cm square. Resistivity can also be checked with a collinear four-point measurement system.

An important consideration for polycrystalline films in the measurement of the electrical characteristics is the assumption of sample homogeneity and uniform film thickness. The resistance associated with grain boundaries and thinner regions of the film can result in errors in the estimation of mobility and doping density. While these effects can be isolated through frequency dependent impedance measurements, modeling of ellipsometric data and thermopower measurements, this is beyond the scope of the current proposal. However, we are able to measure film roughness, grain size and thickness by using profilometry and atomic force microscopy. The Tencor P10 Profilometer will be used for film thickness and initial roughness measurements. More microscopic information can be obtained with a Nanoscope III atomic force microscope.

The above routine measurements can be performed on samples easily once gold contacts are added. For a smaller number of samples grain size and orientation, chemical composition, and optical properties will be measured to obtain a more complete picture, and to provide indication of the contributions of grain boundary, compensation and structural effects. A final set of measurements will be on a completed CdS/CdTe cell. The current density vs. bias (I-V) plot under standard illumination conditions will be examined and compared to cells contacted with ZnTe doped with Cu.

#### Proposed Timeline

December 1999

Start of funding period; mounting of the implantation setup; order placed for missing items; training for Hall system and atomic force microscope January 2000

Ion-implant with initial estimated values for beam flux and ion energy, measure electrical properties and examine effects of annealing on electrical properties February 2000

Complete optimization of implantation; optimize thermal post-treatments March 2000

Complete characterization of best materials; form back contact on CdS/CdTe cell and submit for characterization; complete final report

## Section D

### References

1. T.A. Gessert, A.R. Mason, P. Sheldon, A.B. Swartzlander, D. Niles, and T.J. Coutts, "Development of Cu-doped ZnTe as a back-contact interface layer for thin film CdS/CdTe solar cells," *J. Vac. Sci. Technol. A* 14(3), 806 (1996).
2. J. Tang, D. Mao, T.R. Ohno, V. Kaydanov, and J.U. Trefny, "Properties of ZnTe:Cu thin films and CdS/CdTe/ZnTe solar cells," in *Proceeding of the 26th IEEE Photovoltaic Specialists Conference, Anaheim, CA 1997*, pp. 439-442; L. Feng, D. Mao, J. Tang, R.T. Collins, and J.U. Trefny, "The structural, optical and electrical properties of vacuum evaporated Cu-doped ZnTe polycrystalline thin films," *J. Electron. Materials* 25(9), 1422 (1996).
3. D. Morgan, J. Tang, V. Kaydanov, T.R. Ohno, and J.U. Trefny, "Degradation mechanism studies in CdS/CdTe solar cells with ZnTe:Cu/Au back contacts," *Proceedings of the National Center for Photovoltaics Program Review Meeting, 8-11 September 1998, Denver, Colorado, AIP Conf. Proc.* (1999), 462, pp. 200-205
4. R.G. Bohn, C.N Tabory, C. Deak, M. Shao, A.D. Campaan, N. Reiter, "RF sputtered films of Cu-doped and N-doped ZnTe," *Proc. 24th IEEE Photovoltaics Specialists Conf. (IEEE Hawaii 1994)*, p. 354 (1994).
5. J. Han, T.S. Stavrinides, M. Kobayashi, R.L. Gunshor, M.M. Hagerott, and A.V. Nurmikko, "Heavy p-doping of ZnTe by molecular beam epitaxy using a nitrogen plasma source," *Appl. Phys. Lett.* 62(8), 840 (1993).
6. J.F. Ziegler SRIM 2000, Computer Code, IBM 1998.
7. C.G. van de Walle, D.B. Laks, "Nitrogen doping in ZnSe and ZnTe," *Solid State Communications* 93(5), 447-450 (1995).

## Section E [resumes]

Section F

Proposed Budget

Materials budget– ZnTe chunks, sapphire substrates, gold	\$250
Users fees for instrumentation	\$100
Electronics for ion beam deflection	\$400
Student Award	\$250
Total	\$1,000