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Mercury Cadmium Telluride, Semiconductor Thin Films Prepared by rf Triode Sputtering, Optical and Electrical Properties of Mercury Cadmium Telluride Thin Films.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Improved as-deposited mobility values for rf triode-sputtered thin films of (Hg,Cd)Te, with 25 mole percent CdTe, were obtained by increasing the Hg vapor pressure and the temperature of the single crystal CdTe and Si substrates. Films on single crystal (111) oriented CdTe substrates had the highest as-deposited electron mobility, as determined by four-point probe Hall-effect measurements; values of 2200 and 3720 cm squared per volt sec. with carrier concentrations of 5 and 2.8 times ten to the sixteenth per inverse cubic cm we

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obtained as 296 and 89 degree Kelvin respectively. Using unoptimized procedures, it was shown that the n-type mobility could be appreciably increased. Films with complete (111) crystal orientation and composition of bulk crystals with the same mole percent of CdTe (x value)as that for the pressed-powder targets (made from a mixture of HgTe and CdTe powders) were obtained for x values of 0.1, 0.18, 0.23, and 1.0. ESCA revealed that films with a mixture of (311) and (111) crystal orientations and submicron grain size were deficient in Hg. A nonlinear IV characteristic was measured for a sputtered heterojunction structure.

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2.0 Research Report

2.1 Film Deposition Experiments

Twenty film deposition sputtering runs, with 10 to 15 (111) oriented Si substrates and usually one CdTe substrate in each film set (run), were made between July, 1979 and April, 1980. The effort was aimed at optimizing sputtering parameters to improve as-deposited electrical properties of sputtered films, demonstrating that compositions other than that of 25 mole percent CdTe (i.e., x = 0.25) could be sputtered, and preparing a large number of samples for annealing experiments.

Seven runs were made with 5.7cm diameter targets made by cold-pressing a homogenized powder mixture of HgTe and CdTe to a density of 6.79 g/cm^3 with a pressure of $1.56 \cdot 10^{18}$ newtons/cm^3. The targets had an area of 25.5cm^2 and were of 25 mole percent CdTe. The films had a cut-off wavelength of about 6μm, which corresponds to that for bulk crystal material with x = 0.25. The films were deposited mainly on high resistivity Si and glass substrates and also on a few CdTe single crystal substrates oriented with a (111) surface. [The CdTe substrates are relatively expensive - $140 for a .7cm square oriented single crystal]. The most critical deposition parameters used for most of the runs were: deposition rate, about 4 Å/sec; substrate temperature, 250-300 ^{o}C; Hg pressure 1 to 2.5 microns; r.f. power density, 4.87 (± 5 percent) watts/cm^2; and applied r.f. voltage, 2300 volts. The silicon substrates were etched in hydrofluoric acid and care was taken to minimize reoxidation of the surface during and after insertion into the sputtering vacuum chamber. To make films thicker than previously studied, the deposition time was increased to the 5 to 10 hour range and the film thicknesses were then in the 5 to 10 micron range.

Considerable effort was put into modifying the sputtering system in order to increase the Hg pressure so that the substrate temperature could be raised without losing Hg from the film during the deposition run. After installing heating tape on the walls of the chamber and a control port for the heated bottle of Hg external to the system, it was possible to increase the pressure of Hg used to sputter the target to 3.0 microns. To reach that value, the cooling water to the targets and other parts of the system had to be heated. With the increase in Hg pressure to about 2 microns, films deposited with 250 ^{O}C substrate temperature were not deficient in Hg and did have sufficiently good optical, electrical and structural characteristics suitable for annealing experiments.

Using a 12.7cm diameter hot-pressed powder target of CdTe, purchased from MRC Corporation, and a 5.7cm diameter cold-pressed powder target of CdTe made at NJIT, thin films of CdTe were deposited on Si and glass substrates for the purpose of making high quality, high resistivity films on which CdTe can be grown. The advantage of this approach lies in the fact that the quality of the sputtered films improves as the film grows away from the silicon-sputtered film interface where there is considerable lattice mismatch. CdTe thus could serve either as a buffer layer between film and substrate or as a surface passivation layer. Seven runs were deposited and about twenty films evaluated. Good optical absorption and (111) crystal orientation were obtained, as measured by infrared spectrophotometery and x-ray diffraction. However, the films tended to have small, loose particles on their surface, due to either microscopic peeling effects or loose particles falling from the targets. The target densities were less than 70% of theoretical. It was found that CdTe did not compact under pressure as well as (Hg,Cd)Te or HgTe. A large polycrystalline disc of CdTe was purchased from Two-Six Corp. and will be tested as a target to see if the film results obtained for pressed-powder CdTe targets can be improved.

Films were also deposited onto Si and CdTe using powder-mixture targets having compositional parameter values of x = 0.1, 0.18 and 0.23. The absorption edge of the films were found to be at wavelengths corresponding to those for bulk crystal with the x value of the target; thus the composition of the target was transferred to the sputtered film. The x-ray diffraction results were good; the films had nearly 100% (111) crystal orientation. Preliminary electrical measurements at 296 ^{O}K showed that the films were polycrystalline with mobility values of 1080cm^2/volt.sec for x = .23 films on Si, 672cm^2/volt sec. for x = .18 films and ~1000cm^2/volt.sec for x = 0.1 films. The x =0.1 films behaved as semimetals at 89 ^{O}K, as predicted by the variation of the bandgap of (Hg,Cd)Te with temperature. The x = 0.18 composition parameter was chosen so that the absorption edge at 80 ^{O}K is about 18 microns. It was measured to be 10.4μm at 296 ^{O}K.

2.2 Electrical Properties of As-Deposited Films

Electrical measurements were made by the Van der Pauw, four point probe method. Both clover-leaf geometry samples, obtained by using a small stainless steel mask during (Hg,Cd)Te deposition run, and samples with four contacts on the perimeter of the sample were used. The clover leaf sample is preferred because it eliminates the possibility of the contact material, either evaporated indium or gold, doping the tested (Hg,Cd)Te material. It is also better when the indium dots must be removed for annealing experiments. The perimeter geometry is required for testing samples that have had optical or x-ray measurements made on them. Measurements obtained with indium and gold contact materials were similar; indium was chosen as the contact material because it can be easily selectively etched from (Hg,Cd)Te for annealing experiments.

The lateral mobility of more than twenty as-deposited films were measured in the temperature range of 85-300 ^oK. Low temperature measurements remove thermally generated carriers, which are $6 \cdot 10^{15} cm^{-3}$ at 300 ^oK for x = 0.25 material, and also test the behavior of the mobility compared to defect-free, bulk material, which has a mobility at 85 ^oK that is about 10 times the room-temperature mobility. For films on high resistivity silicon substrates, the n-type mobilities were at first in the 40 to 300 cm^2 per volt sec. range with carrier concentrations varying from $7.1 \cdot 10^{16}$ to $2.1 \cdot 10^{18} cm^{-3}$; at 300 ^oK the mobility was 250 and the carrier concentration $6.7 - 10^{17}$. Several samples on silicon and polycrystalline CdTe substrates were p type at low temperatures. Sample T28-S2 type-converted at 175 ^oK and had p-type carrier concentrations of about $1.0 \cdot 10^{17} cm^{-3}$.

Considerable improvement in as-deposited electrical properties were obtained by increasing the substrate temperature, to enhance the growth of crystal size, while also increasing the Hg vapor pressure, to maintain the Hg concentration in the film. Samples on silicon substrates from runs T50 and T49 had mobilities of about 1100 cm^2/volt.sec. at 296 ^oK and 2700 at 89 ^oK with carrier concentrations of $1.5 \cdot 10^{17} cm^{-3}$ at 296 ^oK and $1.06 \cdot 10^{17} cm^{-3}$ at 89 ^oK. These films were made with substrate temperatures of 300 ^oC, at which temperature poor crystallinity had previously been obtained, and with a Hg pressure of 1.3 to 1.5 mtorr during the run. The samples were also thicker, 8 to 10μm. Somewhat better results were obtained with CdTe single crystal substrates oriented with a (111) surface. At 297 ^{o}K a Hall mobility of 2200cm^{2}/volt.sec with a carrier concentration of only $5 \cdot 10^{16} cm^{-3}$ was measured; at 89 ^{o}K the mobility was 3722cm^{2}/volt.sec and the carrier concentration $2.8 \cdot 10^{16} cm^{-3}$. This film was deposited at 250 ^{o}C. Another film deposited at 300 ^{o}C on a similar CdTe substrate had a mobility of only 990cm^{2}/volt.sec., indicating that the optimum deposition conditions for CdTe and Si substrates may be different. Other significant mobility results were: a value of 1080cm^{2}/volt.sec at 296 ^{o}K for a 5 micron thick film with x=0.23 deposited at 250 ^{o}C with a Hg pressure of 1.4 mtorr; and a value of 940cm^{2}/volt.sec at 296 ^{o}K for a ~ 8 micron thick film deposited at 250 ^{o}C on a silicon substrate with a CdTe buffer layer.

The effects and interactions of substrate temperature and material, Hg pressure, deposition rate, surface treatments including buffer layers and passivation layers, and film thickness must be studied more extensively before final conclusions can be drawn on optimum deposition parameters to obtain the best electrical properties for as-deposited sputtered films. The fact that the n-type carrier concentration did not decrease appreciably from 300 to 85^{o}K (nor did the mobility increase by a factor of 10 as it does for single crystal bulk material) indicated that the tested as-deposited films with thickness in the 1 to 8 μm range had a relatively high concentration of grain boundaries and other defects. The measured lateral mobility and carrier concentrations may not be the actual values for the material between the grain boundaries. Some films with very poor mobilities, less than 100 (cm^{2} per volt sec.) had unstable electrical Hall voltages indicative of trapping effects.

Minority carrier lifetime measurements were made at 300^{o}K on several x=.25 samples using a pulsed GaAs semiconductor laser. The lifetime was measurable, with the 10 nsec. response time of the circuit, only for films with poor electrical mobility and large defect concentrations and trapping effects. Therefore a sample station to be operated at 80^{o}K in a vacuum system was designed. This setup will enable lifetime measurements to be made at temperatures down to 80^{o}K where lifetime is longer for single crystals.

Samples of bulk crystal $(Hg_{.80}, Cd_{.20})Te$ obtained from Peter Brott of Hughes, Santa Barbara were highly polished at Two-Six Corporation for N.J.I.T. Films expected to be p type at $80^{o}K$ were sputtered on these substrates and the film substrate structure was tested for p-n junction behavior by depositing indium contact dots as small as .75 mm diameter. PN junction measurements were made and rectifying nonlinear characteristics obtained for the smallest dots at $80^{o}K$ and $296^{o}K$. The analysis of the heterojunction structure indicated that the film was probably n-type. However, the analysis is complex due to the probable existence of energy spikes at the interface[3], generation-recombination currents due to defects in the depletion region, and various possible reverse-current processes. More experiments and analysis must be carried out before it can be clearly determined if the deposited layers are n-type.

2.3 Electrical Properties of Annealed Films

Film-substrate composites were vacuum-sealed in pyrex tubes containing liquid Hg. The tubes were then heated to $340^{o}C$, for about 12 hours, at which temperature the Hg pressure is 558 torr. Typical results were the following: Sample T-28-S2, which had a maximum p-type mobility of 400 cm^2/volt sec at $125^{o}K$ and n-type mobility of 300 with carrier concentrations of $1.10^{18}/cm^3$ at $300^{o}K$, after annealing had an n-type mobility of 3000 with a carrier concentration of 2.7×10^{17} at $300^{o}K$ and 3700 with an n-type carrier concentration of 10^{17} at $80^{o}K$. The fact that the mobility did not increase to a value at $85^{o}K$ of about 10 times the $300^{o}K$ value indicates that the film is not single crystal. The excess carrier concentration above the intrinsic value also indicates that there are defects in the film probably due to excess Hg. (Note that the films which were previously p-type at $80^{o}K$ were n-type at $80^{o}K$ after the anneal.) Experiments must be carried out to find the necessary anneal temperature for grain growth and the corresponding Hg pressure required without introducing excess Hg into the film. The two-zone furnace purchased for this research will enable the annealing parameters to be separately controlled and optimum annealing parameters determined. Reannealing of previously annealed samples at lower Hg pressures will also be done. [The two-zone furnace was installed and temperature profiles obtained in May, 1980. Higher substrate temperature, lower Hg pressure annealing experiments will commence in June, 1980].

It was found that to prevent the sputtered film from peeling off the silicon substrates, it is necessary to take several hours to raise the temperature to the anneal temperature. The growth of cone-like structures on the surface of some films during annealing was also observed. The composition of these structure will be determine by electron dispersive microbe analysis (EDX) in the SEM at Structure Probe, Inc.

2.4 ESCA Surface Composition Measurements

Research was carried out at Structure Probe, Metuchen, N.J. to characterize the atomic compositions of sputtered thin films. Recent research concentrated on the use of Electron Spectroscopy for Chemical Analysis (ESCA) to avoid the heating and charge effects common to other surface (depths of 20Å) analysis methods such as Auger Electron Spectroscopy (AES), Ion Scattering Spectrometry (ISS) and Secondary Ion Mass Sepectrometry (SIMS). Heating and charging effects have also been observed with the (Hg,Cd)Te films when EDX (electron dispersive micropobe analysis) was used. The ESCA measurements at Structure Probe are done with a model 549 ESCA/AES/SAM surface analysis system manufactured by the Physical Electronics Division of Perkin-Elmer. The measurement consists of knocking out electrons in the orbital shells of atoms (using $MgK\alpha$ x-rays) and sensing the energy of electrons escaping from the top 20Å of the film. A comparison of the electron peak energy with tabulated ESCA photo-electron binding for elements and compounds enables all elements and chemical compounds except H and He to be identified in the analyzed 20Å layer. High-resolution spectra were obtained for the primary elements of interest (Hg,Cd,Te) to show up possible variations in the bound states persent.

The following results were obtained:

1. Films with good optical properties and a high degree of (111) crystal orientation (films from sets T7 and T28 discussed in the 78-79 Progress had surface concentrations of Hg,Cd and Te similar to that for crystal obtained from Hughes Research of Santa Barbara, Calif. These crystals, used as standards, had 25 mole percent CdTe.

2. Films with mixture of 311 and 111 crystal orientations and smaller grain size tended to be deficient in Hg.

3. Several sputtering steps using an Ar^+ ion beam were made with the standard samples to see if the variation of atomic composition with depth could be

obtained. The ion beam etching was done with a 500 V Ar^+ beam to limit charging and beam heating effects. However, it was found that the Hg concentration measured by ESCA decreased considerably due to the effect of sputtering the surface, as was expected.

4. A tellurium oxide compound was found on the surface of the standards and on standards etched with a 5% bromine/95% methanol solution for 10 seconds. The oxide was also found in some film samples but was not present in others. The oxide was believed to exist only in the top 500Å for the standards as it disappeared with ion etching at that depth. The presence of this oxide and other trace impurities in various film samples and their effects on electrical properties are being studied.

3.0 Summary and Future Plans

The experimental results demonstrated that films 1 to 3 microns thick on silicon substrates can have mobilities at 300 °K after annealing comparable to those reported for high-quality thin films in the 2-5 micron range by Polish researchers.[1] However, the mobilities did not increase with decreasing temperature and the low temperature carrier concentrations were higher than expected. This was attributed to the fact that the Hg pressure for annealing was too high, introducing excess Hg into the film. The recently purchased two-zone furnace will enable the Hg pressure and anneal temperatures to be separately controlled, so that the optimum annealing parameters can be determined.

Recent carrier concentration and mobility values for as-deposited films of $5.0 \cdot 10^{16} cm^{-3}$ and $2200 cm^2/volt.\ sec.$ at 296 °K and $2.9 \cdot 10^{16}$ and $3722 cm^2/volt.\ sec.$ at 89 °K indicate that better film results can be obtained presently with CdTe single crystal substrates. The best annealed film results are also likely to be obtained with CdTe substrates because there is only a small mismatch in the lattice parameter and thermal expansion coefficient compared to Si substrates and the peeling problem is not likely to be encountered. Therefore an experimental program has been started where expensive CdTe substrates (~ $140 per substrate) are used for film deposits and annealing experiments and then repolished. The effect of an "A" or "B" surface polishing etch will also be studied.

Although optimization of annealing parameters for films deposited on CdTe substrates, and perhaps also for films on Si, is almost certain to yield (Hg,Cd)Te films with useful properties, an alternate approach of great promise has also been initiated. This approach involves applying the grapho-epitaxy techniques developed at MIT for silicon on amorphous substrates [4] to the heteroepitaxial growth of (Hg,Cd)Te on silicon substrates. Silicon substrates are being anisotropically etched with a V etch, similar to that used in VMOS technology. The samples are being prepared as a senior project by a student, R. D'Angelo, with the V slots separated by a distance less than 10 microns. These silicon substrates, which are slotted to enhance the epitaxial growth of (111) (Hg,Cd)Te will be used as substrates for r.f. sputtered (Hg,Cd)Te (Hg,Cd)Te. Initial results should be obtained by Sept. 1980. High resolution masks and mask alignment equipment is required for this approach.

In addition to improving the electrical properties by annealing, considerable improvement was obtained by making thicker films (5 to 10 microns thick) since the film crystallinity is believed to improve away from the substrate film interface. This opinion is supported by data at N.J.I.T., by mobility versus thickness curves published by Polish researchers for evaporated (Hg,Cd)Te films[1], and by recently published results by French researchers.[2] In fact, if CdTe films can be sputtered with characteristics as good as the (Hg,Cd)Te, $x = 0.25$ films, then it would be desireable to deposit CdTe buffer layers, optically and electrically passive, on the silicon substrates before sputtering the (Hg,Cd)Te layers. Initial results for films sputtered using a hot-pressed five inch CdTe target showed that the films had good x-ray and optical properties; however problems with CdTe films peeling off the Si substrates were encountered. Work on (Hg,Cd)Te - CdTe - Si substrate composites will continue at NJIT. The possibility of using buffer layers other than CdTe should also be investigated.

The results for as-deposited films with x compositional parameter values of 0.1, 0.18, and 0.23, sputtered using a target made from a mixture of HgTe and CdTe powders were encouraging with as-deposited mobilities greater than 2000cm^2/volt.sec obtained at 85 ^oK and desired optical and x-ray properties also obtained. These films will be annealed for the purpose of improving their electrical properties. Also a large number of films of this composition will be triode-sputtered onto Si, single-crystal CdTe and CdTe-coated Si in the near future and studied by ESCA, x-ray, spectrophotometric and Hall-effect measurements. An alternate approach to making long-wavelength thin film material will also be tried. This approach involves sputtering alternate layers of CdTe and HgTe and annealing them in an atmosphere containing partial pressures of Hg and Te.

This approach, with evaporated thin film layers, was reported by Polish researchers to yield high quality material. It would be desirable for this research to compare the properties of triode-sputtered HgTe,CdTe and several (Hg,Cd)Te compositions.

The measurement methods for testing (Hg,Cd)Te thin films are being extended with the fabrication and testing of p-n junction structures, the measurement of minority carrier lifetime over the 80-300 ^{o}K temperature range, and the application of ESCA to compositional analysis of the film surface. The ESCA measurements have pointed out the existence of a tellurium oxide compound on the surface of both sputtered films and bulk-crystal samples. In depth compositional analysis will be obtained by back-etching experiments. The effect of passivation layers, particularly sputtered CdTe, on electrical properties particularly must be studied.

Additional SEM measuremnts of the surface of lightly etched films to measure the size of the polycrystalline grains are an important part of the planned research for the coming year. These measurement will be done particularly to relate the change in mobility of annealed films to increase in crystal size and to other topographical changes, such as the observed growth of cones on the surface of annealed films.

REFERENCES

1. Piotrowska, Anna, Electrical Properties of $Cd_xHg_{1-x}Te$ Thin Films for Hall-effect Device Applications, Electron Technology, Institute of Electron Technology, Warsawa, 1976, pp. 83-120.

2. R. Roussille, A. Zozime, and M. Dupuy, Physical Characteristics of Films of $Cd_xHg_{1-x}Te$ Sputtered on Silicon, le vide-les couches minces, Supplement to volume No. 196, April-May 1979.

3. R.L. Anderson, Solid-State Electronics, 5, 341 (1962), and Henry Kressel and J.K. Butler, Semiconductor Lasers and Heterojunction LEDs, Academic Press, 1977, pp. 62-70.

4. Henry I. Smith and D.C. Flanders, Oriental Crystal Growth on Amorphous Substrates Using Artificial Surface-Relief Gratings, Applied Phys. Letters, vol. 32, No. 6, 15 March 1978, pp. 357-358. Also Silicon Crystals Grown On Amorphous Base, Commerce and Engineering News, Sept. 3, 1979.

5.0 Interactions and Publications

The following oral technical presentations were made in 1979:

1) "Properties of R.F. Sputtered, Mercury Cadmium Telluride Thin Films" by R.H. Cornely, L. Suchow, Dennis DeRidder, Thaddeus Gabara, and Phillip Diodato presented at the Electrochemical Society, Inc. spring meeting in Boston, Mass. May 6-11, 1979 in the Semiconductors and other Electronic Materials Session. Dr. A. Sood of the Honeywell Research Center, Boston was the session chairman.

2) "Electrical Properties of R.F. Triode-Sputtered (Hg,Cd)Te Films" by R.H. Cornely, P. Diodato, T. Gabara, and L. Suchow presented at the National Symposium of the American Vacuum Society on Oct. 4, 1979 in the Thin Films Session. R. Gambino of the IBM Research Center, Yorktown Heights, was the session chairman.

The following publications resulted from the research of this grant:

1) "Properties of R.F. Sputtered, Mercury Cadmium Telluride Thin Films", by R.H. Cornely, Lawrence Suchow, Dennis DeRidder, Thaddeus Gabara, Philip Diodato, Extended Abstracts volume 79-1, Electrochemical Society Meeting, May 6-11, 1979, Boston, Mass., p. 390.

2) "R. F. Triode-Sputtered Mercury Cadmium Telluride Thin Films", by R. H. Cornely, Lawrence Suchow, Thaddeus Gabara, and Philip Diodato, I.E.E.E. Transactions on Electron Devices, Vol. ED27, No.1, January, 1980.

3) The Structural, Optical, and Electrical Properties of R. F. Sputtered ($Hg_{.75}$ $Cd_{.25}$) Te Thin Films, by Philip W. Diodato, thesis for Master of Science degree in Electrical Engineering, at New Jersey Institute of Technology, May 1980.

Informal discussions concerning the (HgCd) Te sputtering research were carried out at the October 4 A.V.S. meetings with Dr. Esther.

Krikorian (General Dynamics Corp., Pomona, Calif.), Dr. Joe Greene (Univ. of Illinois), Dr. Richard Gambino (IBM Research Center) and Dr. Francombe(Westinghouse Research Center). Dr. Greene has considerable experience sputtering GaAs and said that although (HgCd)Te is a more difficult material, he believed that good (Hg,Cd)Te thin films could be obtained by optimizing sputtering parameters, even without using annealing techniques. Dr. Krikorian said that she has started a (Hg,Cd)Te sputtering research project and has obtained as-deposited mobilities on (111) oriented, single crystal CdTe substrates, which are about 30 times more expensive than silicon, that are comparable to our annealed sample results.

At the Electrochemical Society meeting on May 8, Dr. Cornely met with Dr. Ted Wong and Mr. John Miles of the New England Research Center for several hours. All the experimental results on sputtered (Hg,Cd)Te thin films obtained at NJIT up to that time were presented to them in complete detail. Following the oral presentation at the Electrochemical Society meeting, the results were discussed with various members of the Honeywell Research Center in Boston. The following day Dr. Cornely met for two hours with Dr. Sood (of Honeywell Corp.) and discussed in complete detail the (Hg,Cd)Te research at N.J.I.T.

During the past year, particularly valuable discussions have been held with Dr. Maurice Francombe of Westinghouse Labs concerning the electrical results obtained at N.J.I.T. and the various possible annealing approaches. Discussions of the N.J.I.T. research were also held with Lowell Williams (Kuras-Alterman and Raytheon Corp.) and Irwin Kudman of Princeton Infrared Associates, who served as a technical consultant to the research.

Two technical reports concerning HgCdTe material were received from Professor Robert Brebick of Marquette University and one from Professor Fred Polak of Brooklyn College, C.U.N.Y. Further interaction with other scientistis concerned with (Hg,Cd)Te material characterization is expected during the coming year. A copy of a paper on sputtered (Hg,Cd)Te thin films by R. Roussille, A. Zozime and M. Dupuy (of C.E.A. - CENG/LETI 85 x - 38041 Grenoble Cedex and CNRS Bellevue, 92190 Meuden) was received in December 1979. This paper was published in le vide les couces minces (supplement au volume N^{o} Avril - Mai 1979) and presented at the "7eme

Colloque International sur la Pulverisation Cathodique Et Ses Applications". Their films were sputtered on (111) and (100) silicon and had columnar one micron grains with (111) orientation but the electrical properties have not yet been determined.

A grant received from the Army Research Office Durham, N.C., Physics Division, DAAG29-78-G0066 in March, 1978 supports closely related but distinctly separate HgCdTe research. This grant was renewed on March, 1979 and an additional renewal for March, 1980 occurred. The objective of this grant is to develop an understanding of the complex phenomena involved with sputtering the triconstituent target material HgCdTe and to develop practical methods of making good HgCdTe sputtering targets. For this purpose, a large number of different types of targets made from pressed powder mixtures of HgTe and CdTe are fabricated and sputtered under known deposition conditions. The surfaces of these targets are examined and studied by SEM and other surface analysis methods for compositional and topographical changes. The understanding of the target behavior will be very helpful in achieving the objective of the Air Force grant, that is, the growth of single crystal HgCdTe films on inexpensive substrates. The ARO grant is very helpful in achieving this goal by obtaining more detailed scientific knowledge of one of the sputtering parameters, the behavior of the target surface, and by providing additional funds to fabricate the numerous types, of sputtering targets made of the relatively expensive materials, HgTe, CdTe and HgCdTe. Dr. Cornely is the Principal Investigator and Dr. Lawrence Suchow of the Dept. of Chemical Engr. and Chemistry at N.J.I.T. is the Co-investigator of the ARO grant entitled Sputtering Target Research. Dr. Cornely gave a paper on sputtered target research at the American Vacuum Society meeting in Tampa Bay, Clorida on Feb. 11, 1980.

The research reported in this report by the Principal Investigator, Dr. Roy H. Cornely was done by Dr. Cornely assisted by several graduate and undergraduate students in the Electrical Engineering Department. Dr. Lawrence Suchow of the Dept. of Chem. Engr. and Chemistry served in an active role as a most valuable consultant to the program. Mr. Irwin Kudman of Princeton Infrared Associates also served as a valuable consultant. Mr. Philip Diodato, Graduate student, was supported by the

1977-1978 Air Force Grant and received summer support from the 1977-1978 grant. Now employed at Bell Laboratories, Murry Hill, N. J., he has written his MSEE thesis on the electrical, optical and structural properties of (Hg,Cd)Te triode-sputtered films. His thesis was completed in April, 1980. Mr. Tai-On Chan has worked as a graduate student on the (Hg,Cd)Te film research since June, 1979 and has been supported by the 1979-1980 grant since September, 1979. Mr. Thaddeus Gabara, graduate student, was supported by a separate but related grant from the Army Research Office from June, 1978 until September, 1979. Now at Bell Laboratories Murray Hill, N. J., Mr. Gabara was closely involved with all the research reported in this proposal. Mr. Michael Mulligan, now a graduate student, will be supported by the 80-81 Air Force grant as a graduate research assistant. He has worked for several years as an undergraduate research assistant on the (Hg,Cd)Te thin film research. Mr. Riaz Haq, graduate student, has started in October, 1979 MSEE thesis work on the electrical and structural properties of triode-sputtered (Hg,Cd)Te films suitable for detection of long wavelength radiation beyond 18 microns. Mr. Mulligan and Mr. John Hyland did their senior research projects on the topics of pn junction formation and lifetime measurements. Mr. Robert Bourne, graduate student , has worked on the related Army research grant since June, 1979 and is closely involved with many aspects of the (Hg,Cd)Te sputtering research.

6.0 LIST OF PERSONNEL IN 1979-1980 GRANT

Dr. Roy H. Cornely: Principal Investigator, Assistant Professor of Electrical Engineering, N.J.I.T.

Dr. Lawrence Suchow: Advisor, Full Professor in Department of Chemical Engineering and Chemistry, N.J.I.T.

Mr. Irwin Kudman: Advisor, President of Infrared Associates, New Brunswick, N.J.

Mr. Phil Diodato: Graduate Student in Electrical Engineering, half-time academic year 1978-79, two months Summer 1978 and 1979. Graduate Student Assistantship from AFOSR Grant for 78-79 Academic Year.

Mr. Thad Gabara: Graduate Student in Electrical Engineering, half-time academic year 1978-79, two months Summer 1978 and 1979. Graduate Assistantship from Army Research Office Grant for 78-79 Acad. Yr.

Mr. Michael Mulligan: Undergraduate, part-time January 1978 - June 1980 academic year and Summer 1978 and 1979. (Approximately 5 hours per week during academic year.) Supported by NJIT funds.

Mr. Tai-On Chan: Graduate Student in Electrical Engineering, half-time academic year 1979-80, two months Summer 1979. Graduate Assistantship from AFOSR Grant 1979-80.

Mr. Robert Bourne: Graduate Student in Electrical Engineering, half-time academic year 1979-80, two months Summer 1979. Graduate Assistantship from ARO Grant 1979-80.

Mr. Riaz Haq: Graduate Student in Electrical Engineering, part-time work on (HgCd)Te Sputtering Research from October 1979 - June 1980.

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