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This instrumentation proposal is for flip-chip bonding equipment that is essential for bonding the large-format arrays that have been proposed to Si readout integrated circuits (ROICs). At present, no flip-chip bonding equipment is currently available at NCSU, and the flip-chip bonder at NVL is limited in its bonding force such that only diode arrays of up to 64 x 64 pixels can be bonded using indium bump bonds. The proposed flip-chip bonder is designed to bond diode arrays of up 256 x 320 pixels or greater to associated silicon ROICs . In addition, the use of other bonding metals such as lead-alloys commonly used in silicon flip-chip circuitry can be investigated. The use of these alloys in place of indium will permit operation of these new UV imagers at higher temperatures. This will permit use of this new type of UV camera in a variety of Army battlefield environments.

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Sincerely,

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Inclosure 3

FINAL REPORT

DURIP Award DAAD19-00-1-0114

Flip-Chip Bonding Equipment for UV Focal Plane Array Development Based on GaN/AlGaN p-i-n Photodiodes

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PROPOSAL ABSTRACT

Researchers at NCSU have teamed with scientists at the Night Vision Laboratory (NVL) at Ft. Belvoir to demonstrate the world's first visible-blind UV digital camera based on an array of GaN/AlGaN photodiodes. The 32 x 32 focal plane array (FPA) of GaN/AlGaN p-i-n photodiodes was synthesized by MOVPE and processed at NCSU. The FPA was hybridized using flip-chip bonding equipment at NVL. This new imaging device is very responsive to UV radiation in the wavelength band from 320 – 365 nm.

sp → no

Based on work completed to date at NCSU, we see know reason why large-format UV FPAs (256 x 320 pixel or greater) cannot be developed over the next three years. A proposal is being submitted to ARO to develop such large-format UV cameras that sense wavelengths from 280–365 nm. This work will complement ongoing work at NCSU under DARPA support to develop UV cameras that operate in the 250–280 nm solar-blind UV region.

This instrumentation proposal is for flip-chip bonding equipment that is essential for bonding the large-format arrays that have been proposed to Si readout integrated circuits (ROICs). At present, no flip-chip bonding equipment is currently available at NCSU, and the flip-chip bonder at NVL is limited in its bonding force such that only diode arrays of up to 64 x 64 pixels can be bonded using indium bump bonds. The proposed flip-chip bonder is designed to bond diode arrays of up 256 x 320 pixels or greater to associated silicon ROICs . In addition, the use of other bonding metals such as lead-alloys commonly used in silicon flip-chip circuitry can be investigated. The use of these alloys in place of indium will permit operation of these new UV imagers at higher temperatures. This will permit use of this new type of UV camera in a variety of Army battlefield environments.

RESEARCH SUMMARY

All of the funds provided under this DURIP equipment grant have been expended to purchase the following test equipment:

Equipment Item	Estimated Cost
RD Automation M-8G Flip Chip Aligner Bonder – For high pressure aligning and bonding of two samples with facing patterns of solder bumps. Consists of: -- Borescope beamsplitter optical assembly with two reflection illuminators, and two autocollimators. -- Two solid state cameras with superimposed video outputs for alignment on one screen. -- 2" x 2" Lower heated Kovar chuck (to 400 °C) with center vacuum hole and an additional two vacuum rings to hold different size samples. -- Universal upper non-heated chuck with interchangeable pedestals to hold different sample sizes. Includes one pedestal. Sizes to be determined by customer. -- In line force indicator transducer for accurate force readout between two samples. -- Safety features to prevent accidental damage to the samples and optics. -- Microprocessor based control system. -- Variable force joystick, motorized stage and video options. -- Temperature compensated pressure feedback with digital keypad to promote preset contact force and speed control of contact. -- Four programmable cycles: temperature, pressure ramp speed. and soak variables. -- PID temperature controller with automatic process characterization. -- Real time on-screen status report. -- Motorized pitch and roll.	**$220,000**
NCSU Cost-Sharing	**$40,000**
Total DURPIP Funds Expended	**$180,000**

Use of Flip-Chip Bonder. MOVPE growth experiments have been used to optimize growth of AlGaN p-i-n photodiode structures. This has required the development of new MOVPE growth processes for AlGaN, particularly with respect to high Al content (30-65%) AlGaN alloys. To optimize the quality and doping parameters for such layers, a number of characterization experiments were completed after each MOVPE film growth. These include C-V measurement to obtain information concerning net impurity and doping densities, cathodoluminescence experiments to determine the bandgap and, hence, the x-value of the $Al_xGa_{1-x}N$ film, and reflectance/transmittance measurements from 200-900 nm. Certain features in the cathodoluminescence and transmission spectra were identified as being detrimental to photodiode development. Growth conditions (flux ratios, growth rates, and growth temperatures) were systematically varied until these unwanted features were eliminated, hence optimizing the film growth process.

Test photodiodes were prepared using standard nitride device processing procedures in the Central Processing Facility at NCSU. Responsivity and D* measurements were then completed on each test sample to access the overall quality of the diodes (responsivity and UV responsivity band, device sensitivity, etc.). Wafers from which the best diode tests were obtained were then prepared for diode array fabrication. The flip-chip bonder obtained under this DURIP program is being used to hybridize 128x128 and 320x256 arrays to mating Si readout integrated circuits (ROICs). The RD Automation flip chip bonder is shown in Figure 1 below.

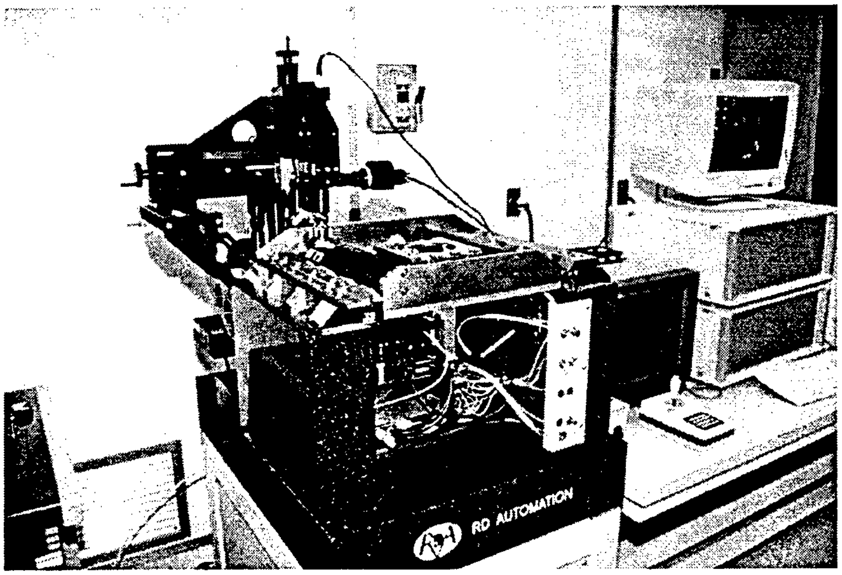

Figure 1. RD Automation Flip-Chip Bonder at NCSU.

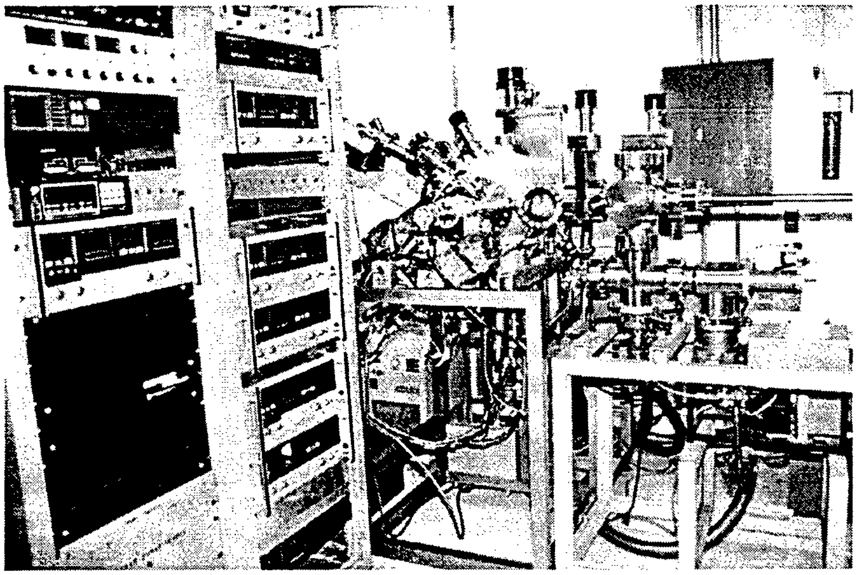

Figure 2. UHV indium bump deposition system at NCSU.

Figure 2 above shows the UHV indium bump deposition system used at NCSU to deposit arrays of indium bumps on both the photodiode arrays and the Si ROICs prior to hybridization. Figure 3 below shows the diode array and ROIC loading onto the platens of the bump bonder just prior to bonding. Figure 4 shows 128x128 and 320x256 hybidized arrays wire bonded to a leadless chip carrier.

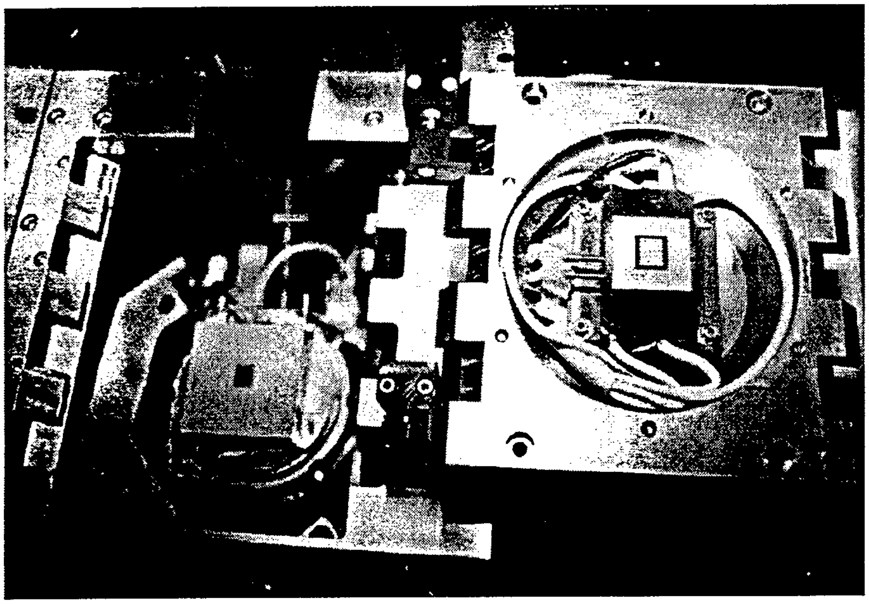

Figure 3. Samples position in flip-chip bonder just prior to hybridization.

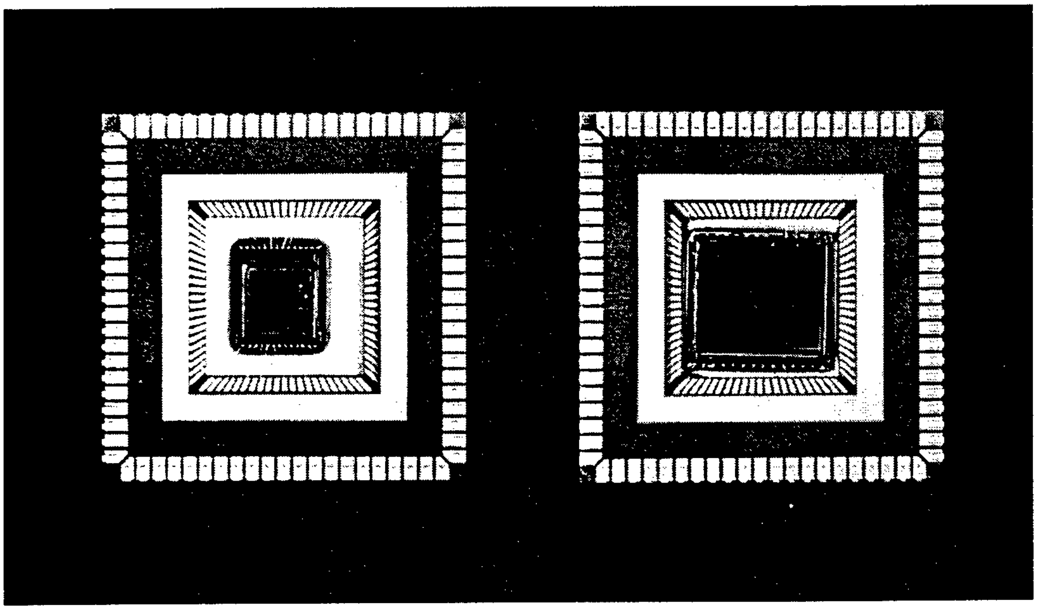

Figure 4. Hybridize 128x128 and 320x256 UV focal plane arrays.

NCSU has developed the entire sequence for processing, bonding and testing UV photodiode arrays using AlGaN heterostructures. Details of these important advances are listed in the publication list below. Under this program NCSU has developed the world's first UV digital imagers using 32x32,128x128, and 320x256 photodiode arrays. More recently, solar-blind (240-285 nm) photodiodes and diode arrays have been demonstrated. These important advancements have been reported at the DARPA Solar Blind Detector program review in March, 2000 in California and at the DARPA Optoelectronics Review in October, 2000 in Cincinnati, OH.

Future Research. We have receive word from ARO that additional research funds will be made available to NCSU for the further development and testing of UV focal plane arrays. Specifically, these funds will be used to prepare and deliver 128x128 and 320x256 UV focal plane arrays to the Night Vision Laboratory at Fort Belvoir, VA for initial field testing of these new UV digital imagers.

RESEARCH PUBLICATIONS

Papers in Refereed Journals

This program for which the DURIP equipment was purchased has produced the following publications. All of our results were submitted to the MRS Internet Journal for Nitride Semiconductor Research, rather than Applied Physics Letters or some other comparable traditional journal, because the MRS journal processes and published papers within about two weeks of submission, the journal routinely publishes color photos, and the research paper is available world wide on the Internet.
Below are the internet addresses of our recent research publications:

http://nsr.mij.mrs.org/4/9/

http://nsr.mij.mrs.org/5S1/W1.9/

http://nsr.mij.mrs.org/5/6/

http://nsr.mij.mrs.org/5/9/

In addition, two papers were delivered at the Boston MRS meeting (November, 2000) and will also soon appear in the MRS Internet Journal.

Invited Presentations

1. "Visible Blind AlGaN Photodiodes and Photodiode Arrays", Solid State Seminar, Duke University, Durham, NC (2000).

2. "UV Digital Cameras Based on 32x32 and 128x128 Arrays of AlGaN p-i-n Photodiodes", 6th Nitride Workshop, Richmond VA (2000).

3. "AlGaN p-i-n Photodiodes for UV Digital Camera Applications", Indigo Systems Corporation, Santa Barbara, CA (2000).

4. "Optoelectronic Applications of III-V Nitride Semiconductors", Physics Colloquium, North Carolina State University, Raleigh, NC (2000).

5. "UV Imaging using AlGaN p-i-n Photodiode Arrays", Physics Colloquium, Montana State University, Boseman, MT (2000).

Student Participation

Two graduate students (J.D. Brown and P. Srinivasan) along with one post doctoral researcher (J. Li) are being supported under this program. J.D. Brown received his PhD degree in Physics in September, 2000 and is currently employed by Nitronix Corporation. His place has been taken by a new graduate student (A. Oberhofer).