MURI 04 ANNUAL REPORT

Consortium on the NanoPhysics of Electron Dynamics near Surfaces in High Power Microwave Devices and Systems

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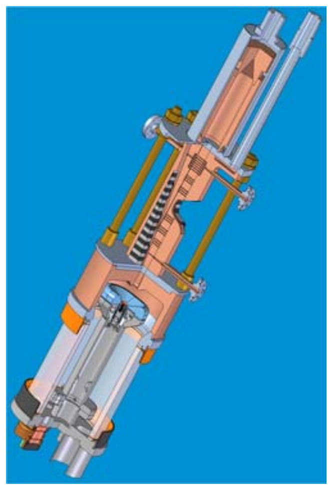

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DIRECTOR'S OVERVIEW

This report covers the period from August 1, 2004 through July 31, 2005 and contains a detailed description of the work conducted by the MURI Consortium on the NanoPhysics of Electron Dynamics near Surfaces in High Power Microwave Devices and Systems. The participating institutions are the University of California, Davis (Lead Institution), Stanford University, and the Naval Postgraduate School, as well as collaborators at CPI, USC, BVERI, IECAS, NTHU, NRL, and NSWC Crane.

The program focuses on basic research aimed at supporting critical DoD needs for successful development of 21st Century HPM devices, specifically a fundamental nanophysics level description and understanding of electron emission and rf breakdown. In the MURI04 program, the Consortium is conducting basic research which is expected to lead to the development of advanced MVED and HPM devices at wavelengths of approximately 30 centimeters and 3 millimeters (and shorter) by acquiring a fundamental understanding of RF breakdown phenomena and by developing novel, high current density cathodes. In addition to the initial MURI funding allotment, additional funding was provided to accelerate the pace of research progress on the cathodes and breakdown studies by permitting us to thoroughly diagnose key cathode and window breakdown physics issues by the design and fabrication of two actual high-power/high frequency (W-Band) devices (namely a gyro-TWT and sheet-beam klystrino) that are of paramount interest to ongoing AFRL/DEH, Navy Sea Systems Command/PMS 405, Lincoln Laboratory, and NRL R&D thrusts. In addition, NSWC Crane personnel are completing two additional devices initiated in the MURI99 program, a TE_{21} Ka-Band, second harmonic gyro-TWT and a Ka-Band second-harmonic Peniotron, which will also provide test-beds for the cathode and breakdown studies as well as contributing to DoD source needs. Finally, preliminary discussions have taken place with JPL concerning the possibility of collaborating in THz source development where the cathode will be an FEA or CNT array.

The two underlying physics issues being addressed under MURI04 are: "pulse shortening" caused by RF breakdown, and the lack of suitable, robust high current density cathodes. RF breakdown is a phenomenon that is poorly understood with respect to both the "nano-physics" of its inception as well the techniques to minimize its effects. Understanding it and preventing it require coordinated experimental and simulation programs. Cathodes are the *sine quo non* of MVEDs of all power levels and frequencies and depend upon new nanofabrication techniques for the continued development required for the next generation of MVEDs which include HPM sources, W-Band gyro-TWTs, compact W-Band sources, and microfabricated millimeter wave and submillimeter wave devices. In addition to these two main thrusts, at the 3 millimeter and shorter end of the spectrum, additional nanophysics issues need also to be illuminated and resolved before a portable millimeter source can be fully developed. For several years, SLAC has been working on such a source, the sheet beam klystrino. Cathode current densities are not a problem for this 2-kW average power tube, but "pulse heating" is. Unlike RF breakdown, which, until recently was thought to be a frequency- dependent phenomenon (and may not be), pulse heating definitely is, and it is severe at millimeter wave frequencies. Recent research at SLAC suggests that initiation of RF breakdown is facilitated by high RF magnetic fields. These fields also result in the RF currents that cause pulse heating. The two phenomena are therefore related and a common solution is being sought as part of the MURI04 RF breakdown research.

To investigate the RF breakdown issue, experiments are being conducted in a resonant single-cell cavity, configured as a "windowtron" and fed directly by a 50-MW X-band SLAC klystron. This arrangement was used in a previous MURI and was found to be much more effective than an earlier method of inserting the cavity in a resonant ring to provide the required sustained power. Stanford is also investigating the breakdown properties of molybdenum structures relative to copper. Copper is widely employed in high power microwave devices and components because of its high electrical and thermal conductivities. However, one drawback of pure copper is its low tensile and yield strengths at room temperature and at elevated temperature. In contrast, Molybdenum is a refractory metal that is easy to machine and is recognized for its excellent strength at high temperatures, its high melting point of 2610°C, its low thermal expandability, its good thermal conductivity, and its low vapor pressure. Initial studies of molybdenum at high gradients included two different rf structures: In the first, a molybdenum iris is mounted into a copper disk which forms a cell with 30 cells clamped together. In the second structure, the entire assembly is brazed together. However, the program has since bifurcated. In the first stem, the TM_{02} cavity is still used for the purpose of comparing the resistance to breakdown of copper, compared to refractory metals such a tungsten and molybdenum. This study does not address the combined effects of rf breakdown and intra-pulse heating; for this, SLAC researchers have been designing an experiment involving a traveling–wave sheet-beam output circuit configured as a quasi-traveling-wave, low-Q circuit with to total voltage developed across it more or less equally divided across the gaps to minimize field gradients. The aim is to test the sheet beam traveling wave circuit in the same experimental setup as the reentrant cavity, also in a windowtron arrangement.

The cathodes required for 30-cm HPM must provide in excess of 100 A/cm^2 and conventional thermionic cathode technology falls short of that current density by about a factor of 5 or greater. Consequently, the cathodes traditionally used are of the "explosive electron emission" (EEE) variety. Unfortunately, the plasmas these cathodes generate can exacerbate RF breakdown. This has motivated extensive efforts to eliminate the deleterious dynamic aspects of EEE cathodes, to replace them with improved conventional cathodes, or to introduce cathodes based on new concepts and ideas. A breakthrough is thus required in both scope and scale. It is noteworthy that suitable 30-cm HPM sources could then be developed by industry, once the fundamental nanophysics issues of RF breakdown and cathode emission are better understood.

Under MURI04, NPS conducted fundamental experimental studies of the EEE process using the Threshold Cathode Test Facility. In support of these studies, a Pierce gun using a CsI-coated carbon fiber cathode has been designed, built, and tested under pulsed conditions in a low 10^{-7} Torr vacuum and durations up to 5 μs using voltages between –80 kV and –110 kV. In order to quantify the gases generated during operation of an explosive emission cathode, residual gas analysis was performed on a closed vacuum system. Two different anode materials were tested using an identical CsI-coated carbon fiber cathode. Use of a transparent molybdenum mesh resulted in the generation of approximately 0.38 neutrals per electron, compared to 0.73 neutrals per electron while using the carbon fiber anode. While the background vacuum pressure was typically in the low 10^{-7} Torr scale, it was found that gas generation during these explosive emission pulses led to local diode pressures of 0.5 mTorr up to several 10’s of mTorr. Such pressures are consistent with the ability to generate ion densities that can drastically affect the space charge-limited current. To aid these experimental emission studies, a simplified picture of space charge-limited (SCL) emission has also been developed.

In a BVERI/Stanford/UC Davis collaboration, a new tungsten/scandate nano-powder which appears to be a major breakthrough in thermionic cathode technology for both conventional microwave tubes and HPM sources. Initial tests have yielded 30-50 A/cm^2 at 850 C which offers the promise of the development of a new class of millimeter wave and THz sources. In addition, this suggests the possibility of 200 A/cm^2 at elevated temperature cathodes which would permit the development of practical HPM sources (1GW for a microsecond as well as greatly increased lifetime at the current densities used in current MVED sources. Through collaboration with CPI and NSWC Crane, cathode buttons are being installed by E-Beam Incorporated in standard CPI life test vehicles for test and evaluation. Testing is expected to commence in September. Here, it should be stressed that if the 850 °C figure is confirmed, this would imply 100 A/cm^2 at 920 °C and 200 A/cm^2 at 980 °C. To place the potential importance into perspective, one should note that the lifetime of standard cathodes operating at 980 °C is >100,000 hours. This is in contrast to the Russian/Calabazas THz BWO cathode which operates at 125 A/cm^2 and possesses an 8 hour lifetime as specified by the Russian manufacturer.

UC Davis is investigating the fabrication of gated FEAs and CNTs. In particular, UC Davis researchers are concentrating on photo-enhanced FEAs which are fabricated in the UC Davis Microfabrication Facility. The UC Davis thrust has been on the fabrication of large arrays (2 cm x 2 cm) of gated p-doped silicon field emitters for gated cathode applications including optical and short wavelength imaging and microwave vacuum electronics as well as in support of the fundamental characterization of electrically and optically gated silicon FEA's. Their improved fabrication process incorporating an 'etch-back' technique resulted in high anode current to gate current ratio and high photocurrent to dark current contrast and sub-nanosecond response time is predicted. Pulsed optical excitation of an FEA from the backside revealed a steep vertical rise time followed by slower rise and fall times. Based on a proposed model, the sub-microsecond rise was attributed to diffusion of electrons, and the slower rise and fall times were attributed to the RC time responses. Temporal analysis of the different regions within the p-type substrate suggested the possibility of sub-nanosecond emission, limited only by the drift of electrons across the depletion layer when series resistances and diffusion electrons were minimized. Thus far, response times of 30 nsec in heavily doped material have been measured and are consistent with the model lending confidence to the sub-nanosecond predictions.

NPS is investigating the fabrication of FEAs and gated CNTs. Specifically, NPS in collaboration with Prof. Gundersen of USC and NRL researchers are designing and eventually will fabricate a novel field emitter array (FEA) structure—JFET (junction field effect transistor)-controlled carbon nanotubes (CNTs). CNTs are attractive since they are stable at high temperatures, can have high electrical and thermal conductivity, and they exhibit ballistic electron transport. Field emission current is extremely sensitive to the local surface's electrical field and work function, so the JFET will limit / stabilize this emission in order to prevent disruptively excessive emission current. The design of built-in JFETs requires the successful interleaving of both the fabrication processes and the semiconductor physics. ATLAS simulation results show that the breakdown voltage of Si JFETs increases with the height of the Si post. This selected Si post structure also improves control of CNT length and allows for thick gate insulators. A fabrication scheme for the JFETs has been developed that is compatible with the final process step of growing CNTs by PECVD at 700 °C. Results from the initial fabrication attempts have been used to improve the mask designs for the next round of FEAs. Through collaboration with colleagues at the Naval Research Laboratory in Washington, DC, CNTs will then be grown and tested on these JFET CNT FEA structures.

UC Davis has modeled, designed and fabricated a completely new ultra high gain gyro-TWT which has been completed and under vacuum and which is awaiting hot test in September. This features diffractive output coupling for full power measurements, 71 dB saturated gain (initially

50 dB gain) to reduce the drive power requirements to MMIC amplifier levels, and distributed loss compatible with the intended high average power operation (110 kW peak, 10 % duty), and 22 % efficiency. The result is a high gain, stable gyro-TWT that can be built by industry for advanced imaging radar systems. Theoretical studies are also being conducted to assess trade-offs between gain, bandwidth, and efficiency since some applications favor the sacrifice of gain from the 71 dB range to provide even wider bandwidth ($\gtrsim$ 8%) despite the increased demands on the driver.

Stanford is also pursuing the development of a 100 kW W-Band device, the W-Band sheet beam klystron (WBSK). Three Stanford graduate students, Mr.Valery Besong, Ms. Kristin Granlund (summer), and Aaron Jensen, have worked on the WSBK. The modeling and mechanical design of the WBSK have been completed. This will operate at 74 kV (instead of the 110 kV of its round beam klystrino predecessor) and can be cooled to supply twice the average power, or 2.5 kW. It will have five times the cooling area at the output cavity compared to the pencil-beam device. Because the sheet beam current density is 144 A/cm^2 compared with 1,200 A/cm^2 for the pencil beam klystrino, the magnetic field is roughly one third of the klystrino magnetic field. This 1,100 G RMS field can be produced by a magnetic circuit that is completely outside the vacuum envelope. The magnets and pole-pieces are rectangular bars that are bonded together and placed in locating slots above and below the RF circuit. It will operate at 1 kHz repetition rate with 20 μs duration pulses and provide 40 dB gain and 40 % efficiency. A WSBK test vehicle consisting of gun, PPM focusing, and simple output has been fabricated and on pump at the time of this writing. It is expected that, on hot test (scheduled for the beginning of September), all of the critical issues such as beam formation, transport, and rf gain will be experimentally confirmed. A major spin-off of this work is the concept of the giga-watt sheet beam klystron (GSBK) for HPM applications which offers many attractive figures such as reduced cost due to the low parts cost and compatibility with grid-modulation if required by applications. This is also an example of the synergism between the cathode and breakdown work and WBSK work and the SLAC ILC work, the latter of which supported SBK studies at 1, 11.4, and 30 GHz thereby providing a sound foundation for exploring GW versions.

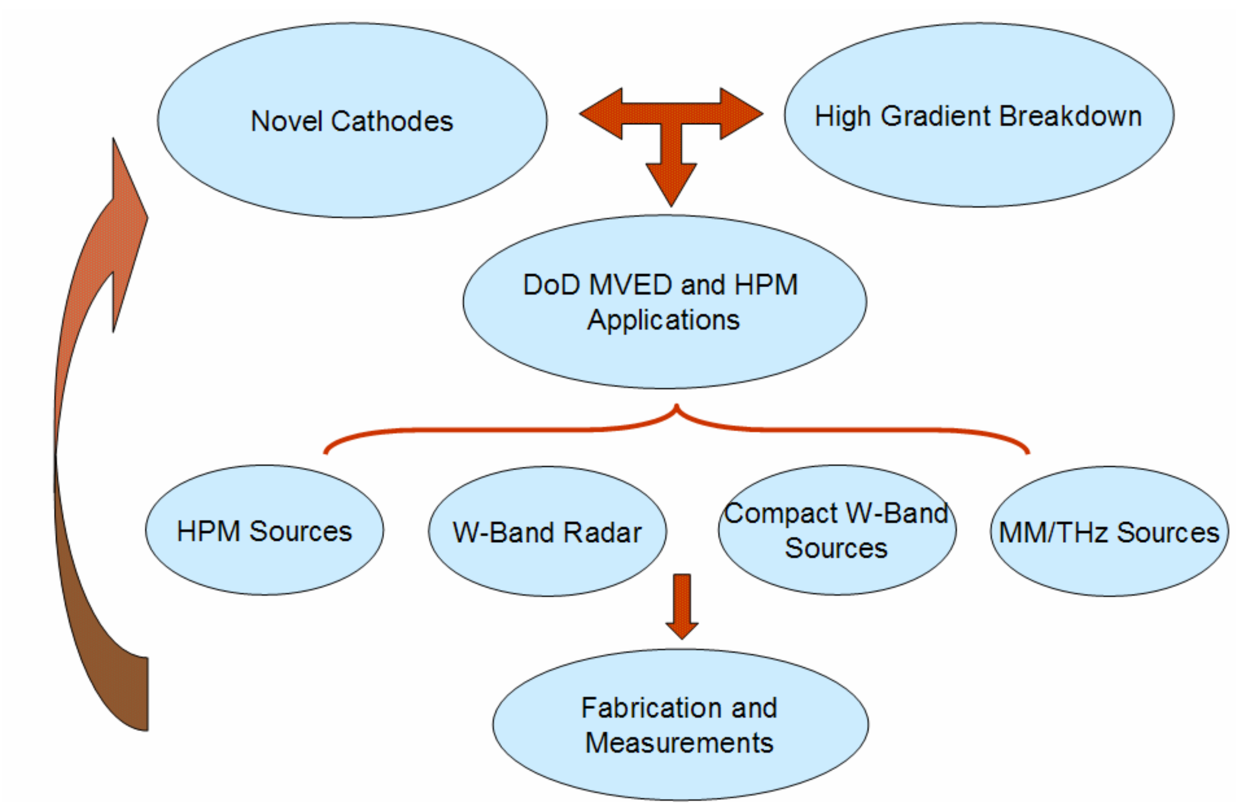
Ms. Hsin-Lu Hsu of UC Davis has begun 3D MAGIC simulations of EIKs and reflex klystrons under Stanford mentoring and preliminary discussions have taken place with the aim of applying this to THz nanoklystrons. Looking to the future, it is hoped to test the FEAs in actual microfabricated millimeter wave and THz sources.

Mr. Lawrence J. Dressman of UCD/NSWC Crane has modeled, designed, fabricated, and cold tested a 34 GHz second-harmonic Peniotron. The design has been optimized for high device efficiency and power output with values of 47% and 125 kW are predicted by large-signal simulation. Simulation also predicts that the overall efficiency can be increased to 57% with the addition of a depressed collector. The device requires a 6.5 kG axial magnetic field, a value still within the limits of conventional magnet technology. Looking ahead, the plan is to extend the operating frequency to W-Band while continuing to employ low magnetic field through the use of higher harmonic interactions.

Mr. Stephen Harriet, also of UCD/NSWC Crane, has modeled, designed, and is in the final fabrication stages of a second-harmonic TE_{21} Ka-Band Gyro-TWT, which employs an axis-encircling electron beam is used that is produced by a novel cusp electron gun developed and delivered by Northrop Grumman under previous MURI/DURIP funding. The single stage second-harmonic gyro-TWT amplifier operates with 70 KV beam voltage and 3.5 A beam current and is predicted to produce 50 kW with 20% efficiency, 30 dB saturated gain and 3%

saturated bandwidth. The magnetic field requirements are reduced by a factor of two with the envisioned eventual W-Band device to operate at higher harmonics, thereby taking further advantage of the characteristics of harmonic operation.

The MURI04 program is well integrated. As illustrated in the figure below, fundamental research on novel cathodes and high gradient rf breakdown is being conducted which is guided by DoD MVED and HPM applications. The ubiquitous nature and importance of the cathode and breakdown subjects is seen by the spectrum of source applications ranging from low power THz sources to GW HPM microwave sources which directly benefit from the MURI results.



The PIs from all three institutions attended the 5th International Vacuum Electron Sources Conference IVeSC2004 in September 2004, Beijing, China. Here, Prof. Luhmann gave an invited talk entitled "Western Consortium on the NanoPhysics of Electron Dynamics near Surfaces in High Power Microwave Devices and Systems". In addition, since many of the world's cathode experts were present, a main focus of the MURI04 attendees was on establishing new collaborations. This resulted in the abovementioned tungsten/scandate nanopowder collaboration.

The UC Davis work was well represented by three of the graduate students at the Sixth IEEE International Vacuum Electronics Conference (IVEC 2005), April 20-22, 2005, Noordwijk, Netherlands. Here, Ms. Hsin-Lu Hsu presented a talk on the MAGIC3D modeling work and Mr. Stephen Harriet and Mr. Lawrence Dressman presented posters on the second harmonic gyro-TWT and peniotron activities, respectively. At the 32nd IEEE International Conference on Plasma Science (ICOPS 2005), June 18-23, 2005, Monterey, California, Ms. Q. Shui of USC presented a poster on the joint NPS/USC/NRL work on JFET-controlled carbon nanotube field emitter arrays. Professor Luhmann was one of the Co-Organizers of RF 2005: The 7th International High Energy Density and High Power RF Workshop, June 13-17, 2005, Kalamata, Greece. The Workshop was jointly sponsored by the US Department of Energy and the European Office of Aerospace Research and Development of the USAF and the proceedings will be published by the AIP. Here, Stanford presented a paper on the W-Band microfabricated sheet beam klystron and UC Davis presented a paper on the 94 GHz gyro-TWA development as well as posters on the second harmonic gyro-TWT and peniotron activities. Both NPS and UC Davis were represented at IVNC 2005: The 18th International Vacuum Nanoelectronics Conference, 10-14 July 2005, Oxford, UK. Here, presentations were made on both the photoenhanced FEA work and the JFET-controlled carbon nanotube field emitter arrays. Finally, both UC Davis and Stanford will be presenting papers at the Joint 30th International Conference on Infrared and Millimeter Waves and 13th International Conference on Terahertz Electronics (IRMMW-THz), September 19-23, 2005, Williamsburg, Virginia and the Tri-Service VED Workshop, 13-15 September 2005, Albuquerque, NM which will be reported in the next Review.

In addition to frequent email and phone interactions as well as laboratory visits and full laboratory joint investigations amongst the Consortium members, there exists close interactions with industry and government laboratories, thereby ensuring efficient transfer of the MURI results.

PROGRAM DESCRIPTION

The MURI Consortium is conducting a coordinated program of theoretical, computational, and experimental investigations aimed at fundamental understanding of the nanophysics issues of RF breakdown and cathode emission, determination of underlying physics and subsequent development of advanced robust HPM components, integration with pulsed technology, together with appropriate technology advances to make possible industrial production of HPM sources. This includes the development and fabrication of actual devices of DoD relevance in which key cathode and rf breakdown physics issues may be diagnosed. UC Davis is the overall program host with Prof. N.C. Luhmann, Jr. serving as the Principal Investigator for MURI04. The separate component tasks of the program are as follows:

- NPS, UC Davis, and Stanford are collaborating to produce laser-deposited oxide and scandate thermionic cathodes predicted to yield emission current densities up to 200 A/cm^2. This activity utilizes the Stanford and UC Davis cathode fabrication and diagnostic facility. In addition to cathodes fabricated by the MURI team, the group has been proactive in establishing collaborations so that a broader range of cathodes may be evaluated. In a BVERI/Stanford/UCD collaboration, a new tungsten/scandate nano-powder which appears to be a major breakthrough in thermionic cathode technology for both conventional microwave tubes and HPM sources. Initial tests have yielded 30-50 A/cm^2 at 850 C which offers the promise of the development of a new class of millimeter wave and THz sources. In addition, this suggests the possibility of 200 A/cm^2 at elevated temperature cathodes which would permit the development of practical HPM sources (1GW for a microsecond as well as greatly increased lifetime at the current densities used in current MVED sources. Through collaboration with CPI and NSWC Crane, cathode buttons are being installed by E-Beam Incorporated in standard CPI life test vehicles for test and evaluation in a cathode life test facility provided by CPI.

- A major focus of the NPS MURI04 program has been fundamental investigations of the explosive emission process. In support of these studies, a Pierce gun using a CsI-coated carbon fiber cathode has been designed, built, and tested under pulsed conditions in a low 10^{-7} Torr vacuum and durations up to 5 μs using voltages between –80 kV and –110 kV. In order to quantify the gases generated during operation of an explosive emission cathode, residual gas analysis was performed on a closed vacuum system. Two different anode materials were tested using an identical CsI-coated carbon fiber cathode. To aid these experimental emission studies, a simplified picture of space charge-limited (SCL) emission has also been developed.

- NPS and UC Davis are investigating the fabrication of FEAs and gated CNTs. The UC Davis researchers are concentrating on photo-enhanced which are fabricated in the UC Davis Microfabrication Facility. The NPS work is being carried out in collaboration with Prof. Gundersen and NRL researchers with the devices fabricated in the USC nanofabrication facilities. In this effort, a novel field emitter array (FEA) structure—JFET (junction field effect transistor)-controlled carbon nanotubes (CNTs)—is being designed and fabricated. Recently, a carbon nanotube growth chamber was obtained using DURIP funds and will be set up at NPS. The UC Davis thrust has been on the fabrication of large arrays (2 cm x 2 cm) of gated p-doped silicon field emitters for gated cathode applications including optical and short wavelength imaging and microwave vacuum electronics as well as in support of the fundamental characterization of electrically and optically gated silicon FEA's. Their improved fabrication process incorporating an 'etch-back' technique resulted in high anode current to gate current ratio and high photocurrent to dark current contrast and sub-nanosecond response time is predicted.

- The thermionic, field emission and special cathodes are being evaluated over the full spectrum of DoD relevance in SLAC designed test-vehicles specifically aimed at the MURI04 program goals. Modulators are provided by UCD and CPI is providing an entire cathode emission life tester. Further assistance is providing by NSWC Crane which administers the TriService/NASA Cathode Life Test Facility (CLTF). In addition to the new test-vehicles, the NPS Threshold Cathode Test Facility was utilized for the collaborative MURI investigations.

- Theoretical, computational, and experimental investigations of RF breakdown are being conducted by Stanford. This includes the investigation of the breakdown properties of molybdenum structures relative to copper. Copper is widely employed in high power microwave devices and components because of its high electrical and thermal conductivities. However, one drawback of pure copper is its low tensile and yield strengths at room temperature and at elevated temperature. In contrast, Molybdenum is a refractory metal that is easy to machine and is recognized for its excellent strength at high temperatures, its high melting point of 2610°C, its low thermal expandability, its good thermal conductivity, and its low vapor pressure. Initial experiments involved a molybdenum iris is mounted into a copper disk which forms a cell with 30 cells clamped together. In the second structure, the entire assembly was brazed together. However, program has since bifurcated. In the first stem, the TM_{02} cavity is still used for the purpose of comparing the resistance to breakdown of copper, compared to refractory metals such a tungsten and molybdenum. This study does not address the combined effects of rf breakdown and intra-pulse heating; for this, SLAC researchers have been designing an experiment involving a traveling–wave sheet-beam output circuit configured as a quasi-traveling-wave, low-Q circuit with to total voltage developed across it more or less equally divided across the gaps to minimize field gradients. The aim is to test the sheet beam traveling wave circuit in the same experimental setup as the reentrant cavity, also in a windowtron arrangement.

- In addition to the initial MURI funding allotment, supplemental funding was provided to accelerate the pace of research progress on the cathodes and breakdown studies by permitting us to thoroughly diagnose key cathode and window breakdown physics issues through the design and fabrication of a completely new W-Band gyro-TWT. This was designed and fabricated by UC Davis and will be hot-tested beginning in September. The initial device is designed to produce 110 kW (with design rules consistent with 10% duty) with 50 dB gain, 5% bandwidth, and 22% efficiency. Design and modeling activities have shown that it will be relatively simple to extend this to ultra-high gain (70 dB) which would permit DoD radar amplifiers to be driven directly from a solid-state MMIC chip. The device directly addresses DoD needs for advanced millimeter wave radar sources, specifically radars such as WARLOC, Haystack.

- To further accelerate the pace of research progress on the cathodes and breakdown studies, supplemental funds were provided which, together with major DOE funding, permitted Stanford to design and fabricate a PPM focused, W-Band sheet beam klystron (WSBK) also predicted to produce 100 kW peak. The specific design parameters are: 100 kW peak power with 20 μs pulse duration, 1 kHz repetition frequency, 2.5 kW average power output, 40 dB gain, and 40 % efficiency. A WSBK test vehicle consisting of gun, PPM focusing, and simple output has been fabricated and on pump at the time of this writing. It is expected that, on hot test (scheduled for the beginning of September), all of the critical issues such as beam formation, transport, and rf gain will be experimentally confirmed.

- NSWC Crane personnel (Larry Dressman and Stephen Harriet) are completing two additional devices initiated in the MURI99 program, a TE_{21} Ka-Band, second harmonic gyro-TWT and a Ka-Band second-harmonic Peniotron (to be hot tested in October, 2005), both of which will also provide test-beds for the cathode and breakdown studies as well as contributing to DoD source needs.

- Finally, it is hoped to test the FEAs in actual microfabricated millimeter wave and THz sources. To that end, graduate student Hsin-Lu Hsu has begun 3D MAGIC simulations of EIKs and reflex klystrons and preliminary discussions have taken place with the aim of applying this to THz nanoklystrons.

In the following, the progress in each of these areas will be described. This is followed by Appendix A which contains the program for the 5th International Vacuum Electron Sources Conference IVeSC2004, was held in September 2004, Beijing, China. Here, Prof. Luhmann gave an invited talk entitled "Western Consortium on the NanoPhysics of Electron Dynamics near Surfaces in High Power Microwave Devices and Systems". In addition, since many of the world's cathode experts were present, a main focus of the MURI04 attendees was on establishing new collaborations. This resulted in the abovementioned tungsten/scandate nanopowder collaboration. The UC Davis work was well represented by three of the graduate students at the Sixth IEEE International Vacuum Electronics Conference (IVEC 2005), April 20-22, 2005, Noordwijk, Netherlands (see Appendix B for program). Here, Ms. Hsin-Lu Hsu presented a talk on the MAGIC3D modeling work and Mr. Stephen Harriet and Mr. Lawrence Dressman presented posters on the second harmonic gyro-TWT and peniotron activities, respectively. At the 32nd IEEE International Conference on Plasma Science (ICOPS 2005), June 18-23, 2005, Monterey, California, Ms. Q. Shui of USC presented a poster on the joint NPS/USC/NRL work on JFET-controlled carbon nanotube field emitter arrays. Professor Luhmann was one of the Co-Organizers of RF 2005: THE 7th INTERNATIONAL HIGH ENERGY DENSITY AND HIGH POWER RF WORKSHOP, June 13-17, 2005, Kalamata, Greece (see Appendix C for program). The Workshop was jointly sponsored by the US Department of Energy and the European Office of Aerospace Research and Development of the USAF and the proceedings will be published by the AIP. Here, Stanford presented a paper on the W-Band microfabricated sheet beam klystron and UC Davis presented a paper on the 94 GHz gyro-TWA development as well as posters on the second harmonic gyro-TWT and peniotron activities. Both NPS and UC Davis were represented at IVNC 2005: The 18th International Vacuum Nanoelectronics Conference, 10-14 July 2005, Oxford, UK. Here presentations were made on both the photoenhanced FEA work and the JFET-controlled carbon nanotube field emitter arrays. Finally, both UC Davis and Stanford will be presenting papers at the Joint 30th International Conference on Infrared and Millimeter Waves and 13th International Conference on Terahertz Electronics (IRMMW-THz), September 19-23, 2005, Williamsburg, Virginia and the Tri-Service VED Workshop, 13-15 September 2005, Albuquerque, NM which will be reported in the next Review.