DEPARTMENT OF MATHEMATICS

VIGRE Funding Report

(due 30 days after semester of support)

Semester/Summer and Year: FALL/2008

Name: BRIDGET KENNEDY

List the graduate courses you have taken this semester (including independent studies), your grades, and the instructors:

Course	Title	Grade	Instructor
MATH 920	DISSERTATION	S	GABITOV

List the title, date and location of any talks you have given, either here or elsewhere:

If you are working on your dissertation, include a one paragraph description of your research progress. If you have not yet begun dissertation research, describe your progress toward finding a dissertation topic and advisor and beginning that research.

In the fall I began work on my dissertation. Until last semester I had been reading background material and working on "toy" problems, but this past semester I worked on a specific example of a left-handed metamaterial. The goal of my dissertation is to develop an appropriate method of loss-compensation for these new materials, which are known to exhibit great loss in experiment. The "toy" problems that I examined in the past have dealt with compensation of loss where the loss was a constant drain to the electric field. The loss to the system, in these problems, was thrown in to the model of a system, but did not come from the specific loss of the material equations. This past semester I derived the governing equations for a structure of split-ring resonators in the presence of active atoms. These active atoms were used as the gain material and were embedded to the dielectric. After deriving the governing equations I modified some preexisting Matlab code to solve these equations, and I was able to see the creation of a solitary wave when a small initial pulse was sent into the system.

List publications, if any.

Check all activities you completed during the funded period:

Academics:

- [ ] Independent Study
- [ ] Oral Comprehensive Exam
- [x] Commence Thesis Research
- [x] Conference attendance
- [ ] Conference participation
- [ ] Complete PhD

Professional development and outreach:

- [ ] AP Calculus Visit
- [x] High School Workshops
- [ ] Undergraduate Research Project
- [ ] Undergraduate Research Seminar
- [ ] Super TA
- [ ] Mentoring junior graduate students for the qualifying exams
- [ ] RTG (help organize)
- [ ] Research Seminar (help organize)

- [ ] Other (please specify)

Attach a brief statment about your academic progress and professional development during the period of support.

VIGRE REPORT PART II

Research

In the fall I began work on my dissertation problem. I had, until last semester, been dealing with loss compensation of so-called left-handed metamaterials without specific choice of a metamaterial that exhibits this unusual property. I had understood how electromagnetic resonance was used to create negative refractive index (NRI) materials, but I had yet to study a specific example in detail.

In my dissertation research I derived governing equations that described the interaction of an incident pulse with an array of split-ring structures and metallic rods embedded into a dielectric. The split-rings and rods create both an electric and magnetic resonance, which allows the material to achieve both a simultaneous negative permittivity and permeability, and therefore, will exhibit anti-parallel phase and group velocity in this medium (left-handed material). Since an electric and magnetic resonance is required to obtain this simultaneously negative response of the system, the interaction of the incident pulse with the metamaterial will cause the pulse to decay. The ability to observe the very unusual properties that results from anti-parallel group and phase velocities has been greatly hindered by the large drain of the intensity of the incident pulse, and the need to correct for these losses must be overcome for further work in this field to progress.

In my work last semester my advisor and I took the specific case of a split-ring array and suggested the addition of active atoms or quantum dots into the dielectric host medium. We proposed to do this in two ways. First, we considered inserting active atoms into the dielectric material as a whole, and secondly, by adding these inclusions across the gap in the split-ring. Since the electric field across the gap of a split-ring is much stronger here than elsewhere in the medium, one would be much better able to pump the electric field by inserting a source of gain across the gap in the split-ring. Since the addition of active atoms to the dielectric, rather than to the gap, is simpler to model we began there.

I derived equations that model the interaction of an incident pulse with an array of split-rings and rods, and showed that for specific frequencies both the permittivity and permeability will be negative. I then considered the addition of the active atoms embedded to the dielectric, whose interaction with the material is described through the Maxwell-Bloch equations. The resultant governing equations for the system are the material equations that describes the doubly-resonant interaction of the material with the incident pulse, which gives the loss term to the system of partial differential equations, and the Maxwell-Bloch equations that describes the gain introduced to the system by the active atomic inclusions. In this system I considered the active atoms to be two-level atoms.

Once these equations were derived, I modified an older code that was used in a similar simpler system whose governing equations ignored loss. Since the active atoms were considered to have two-levels, an excited and a ground state, I let the code assume that the active atoms within the material were all initially in the excited state. Given a small initial pulse (the incident pulse on the array) the code produced a shock wave that, once its maximum height was reached, propagated at the same velocity and shape throughout the material (the creation of a solitary wave solution). In addition, I was able to see that in the absence of these active atom inclusions, even an initial pulse of great intensity decayed to nothing as it passed through the array. I could also observe that the resultant pulse corresponded to the transition of the active atoms from the excited state to their ground state.

The next step in my research will be to insert active atoms across the gap, and to derive the governing equations for this situation. I am currently looking for an analytic solitary wave solution to this equation that corresponds to the solitary wave observed in the code. I will also be studying metallic nano-horseshoe structures embedded in a dielectric, which have been shown to exhibit left-handed properties in the optical domain.