ND*nano* Undergraduate Research Fellowship (NURF)
2014 Project Summary

1. Student name: Luis Enrique Cortés Herrera

2. Faculty mentor name: Anthony Hoffman

3. Project title: Design of a quasichaotic optical multipass cell

4. Briefly describe any new skills you acquired during your summer research:
- I learned to formulate wave propagation problems as an equivalent ray dynamics problem under the short wavelength approximation.
- I learned to employ visualization schemes to analyze nonlinear mechanics of a Hamiltonian system.
- I learned to analyze the transition of an integrable Hamiltonian system to chaos following KAM theory.
- I learned to use simulation and analytical methods to analyze a dynamical system's Liapunov stability.
- I learned to implement efficient quasi-Newton methods with global convergence for constrained optimization and solution of nonlinear equations.
- I learned to synthetize simulation results by fitting global behavior to a mathematical model to efficiently extract relevant information for engineering applications.

5. Briefly share a practical application/end use of your research:
Optical multipass cells generate a long stable optical path that is desirable for optical gas sensing applications because long optical paths increase the interaction of light with the gas under test, resulting in improved sensing. In particular, multipass cells with quasichaotic ray dynamics consisting of a single closed surface are advantageous compared to more traditional multipass cells because they are highly compact, require only trivial alignment, and are cheap to manufacture.

Project summary:
Multipass optical cavities are widely used for applications in optical sensing because long path lengths increase the detection sensitivity of the systems. The most commonly used multipass cells are based on integrable dynamics using paraxial ray approximations, where integrability means that analytic descriptions of the ray dynamics can be specified.   However, these optical systems have two major limitations: they consist of multiple focusing elements, which make their alignment nontrivial, and they must be of considerable length—on the order of tens of centimeters—for the ray dynamics to follow the paraxial ray approximations. To overcome these constraints, an optical cavity consisting of a single closed surface with quasichaotic ray dynamics is useful.

In my research, I analyzed the nonlinear ray dynamics of a quadrupole-shaped cavity and engineered the shape of the cell to obtain optical paths with greater length, stability, and global focusing. We model the optical beam as a point particle in a quadrupole-shaped cavity following

the geometrical optics approximation, simulate its behavior under multiple reflections, and interpret the trajectory using the nonlinear classical dynamics formalism. We demonstrated that the stability of the transversal modes can be modeled as a simple function of the deformation variables, which makes it possible to find optimal quadrupole shapes for sensing applications. This work represents a method to engineer complex, nonlinear ray dynamics for the realization of gas cells with highly desirable optical characteristics.

Publications (papers/posters/presentations): As the product of this research, a poster was presented at the Summer Undergraduate Research Symposium 2014 at the University of Notre Dame. Also, a paper will be written in the following months in which the results obtained and their impact on optical multipass quasichaotic cell design will be discussed.