In 1998, Bender and Boettcher found that a wide class of Hamiltonians, even though non-Hermitian, can still exhibit entirely real spectra if they obey parity-time requirements or PT symmetry.
Parity Time ($PT$) Optics

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PT-Optics

PT-symmetry system

Real part: even
Imaginary part: odd

Gain = Loss

One example a PT Optical Potential is the PT directional coupler

Gain = Loss

Index
Gain/loss

x
Passive $PT$ directional coupler

Experiment measurable --- Output Power

- Lossless
- Total Output Power
- Loss
How should we make the PT directional coupler?

Gain = Loss
We rely on Nanoscience

The effort to understand and design structures at the nano size and seek their application

Line up 50 atoms end-to-end and you get one nanometer

Take the diameter of a hair and divide by 100,000 and you have a diameter of nanometer size
Why Nanoscale Materials
Take any element or compound

and cut it in half, and then half again ... and yet in half again .... until you have nanosize

Element in the Periodic Table

Same element but totally different properties
The Search for Underlying Rules at the Nanoscale

the same element or compound will have very different optical, electrical, or mechanical properties depending on its size!

CdSe – but each a different size!
Why this Change in Behavior?

New Rules When We Go

Easy to Cause Flow

If it’s Small it is Difficult to Cause Flow

?
One of our Arkansas Growth & Fabrication & Imaging Facilities
Molecular Beam Epitaxy (MBE)

Source of Atoms

Beam of Atoms

Mono-Layer

substrate

Heater
What Nanoscience can do for you in research
Explore the new rules at the nanoscale

![Strain relaxation](image1.png)

- **InAs**
  - Strain relaxation
  - Surface energy

**Starting GaAs**

- **2.1 ML InAs on AlAs**
  - 200 nm x 200 nm

- **2.2 ML InAs on AlAs**

Stable surfaces or facets

*13.5 nm*

*0 nm*
Scanning Tunneling Microscopy (STM)

Piezo

Bias

= 5 Å

A
Even More Than Size = New Behavior! We can form Molecules or Chains or Solids made of Quantum Dots.
Color in a peacock feather

Arkansas Grown Quantum Dots

Dots in a Peacock Feather
How should we make the PT directional coupler?
Design of a PT Coupler

Tuning loss by Varying Cr-Width

The introduction of loss must be done in way that does not perturb the even refractive profile. This is physically demanding since the presence of loss is typically accompanied by an index perturbation (because of the Kramers-Kronig relations).
ESEM image of one PT coupler

Top-view: Loss = 35 cm$^{-1}$
Cr width = 4 μm
Experimental Set-Up

- IPG Fiber Laser
- Cylindrical Telescope
- X40 Obj
- X20 Obj
- Sample
- Aperture
- Detector
- B.S
- IR Camera
- Ar Laser
- Camera
- Sample image (top)
Loss of Isolated waveguide structure as a function of Cr width
Experimental observation of $\mathcal{PT}$-symmetry breaking
Conclusions

• We show for the first time that passive PT-symmetry breaking can be observed within the realm of optics.

• This abrupt phase transition leads to a counterintuitive loss induced optical transparency in specially designed pseudo-Hermitian potentials.
NEED CASH for PT RESEARCH
Schrödinger-like equations appear in optics (paraxial equation)

\( \mathcal{PT} \) symmetry in QM \hspace{1cm} \mathcal{PT} \) symmetry in Optics

Potential \( V(x) \)

Index of refraction \( n(x) \)
Passive $PT$ directional coupler

Experiment measurable --- Output Power

- Lossless
- Loss
- Total Output Power
Real and imaginary parts of the optical dielectric function of Cr

At 1.55μm, the metal leads to heavy losses while the real part of index mismatch at minimum!

Choose Cr:

At 1.55mm, the metal leads to heavy losses while the real part of index mismatch at minimum!

\( PT \) directional coupler supermodes below and above phase transition

\[
\begin{align*}
\text{Loss} &= \text{Gain} \\
\text{below phase transition} & & \text{above phase transition}
\end{align*}
\]
Passive $PT$ directional coupler: $\text{Gain} = 0$

Gain = Loss

\[\text{Lossless} \quad \text{Loss}\]
Passive $\mathcal{PT}$ directional coupler: $\text{Gain} = 0$

Lossless (Gain=0) and Loss

below phase transition

above phase transition
Passive $\mathcal{PT}$ directional coupler

Supermode at $z$ (below phase transition)
Passive $\mathcal{PT}$ directional coupler

Experiment measurable --- Output Power

Input

\[ \text{Supermode at } z \text{ (above phase transition)} \]