Spatial Optical Circulator Structure



Overview

This research proposes a practical multiport optical circulator design by using polarizing beam splitter cubes as spatial walk-off polarizers.

Key Takeaways

A spatial optical circulator is a multi-port, nonreciprocal device that routes light sequentially between ports using magneto-optical effects, Faraday rotators, or photonic crystal cavities.

Basic Structure and Operation

A typical optical circulator has three or four ports, where light entering one port exits the next in a cyclic manner. For example, light entering port 1 exits port 2, and any reflected light from port 2 is directed to port 3 rather than returning to port 1, ensuring nonreciprocal transmission. This behavior is achieved by breaking time-reversal symmetry, often using a Faraday rotator or magneto-optical materials.

Fiber and Waveguide Implementations

In fiber-based systems, the circulator can connect single-mode (SM), double-clad (DC), and multimode (MM) fibers, allowing sequential routing of optical signals while maintaining high isolation and low insertion loss. Waveguide-integrated circulators use evanescent coupling to a resonant cavity, where the cavity supports counterrotating modes at different frequencies. Proper matching of the cavity mode splitting with waveguide coupling enables ideal three-port circulation with complete isolation.

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Photonic Crystal and Magneto-Optical Designs

Spatial optical circulators can also be implemented using two-dimensional magneto-optical photonic crystals. The central cavity is surrounded by three waveguides arranged with 120° rotational symmetry, and the cavity supports two counterrotating states. By engineering the magnetic domain structure, the device achieves directional light propagation along a single path, suppressing backscattering and reflections.

Topological photonic crystals further enhance robustness against defects and sharp bends, enabling compact, planar, and broadband circulators.

Polarization Considerations

Early circulators were polarization-dependent, requiring specific linear input states. Modern designs achieve polarization-independent operation using polarization-diversity schemes, such as combining multiple prisms and reciprocal polarization rotators, ensuring high isolation and low loss across different polarization states.

Free-Space Optical Circulators

For free-space optical systems, spatial circulators can route light between fibers and free-space beams. A single-mode fiber can inject a Gaussian beam into the circulator, which is then directed into a multimode fiber for relaxed alignment requirements. This allows colorless operation, meaning the system does not require predetermined wavelengths for transmission and reception.

Summary

Spatial optical circulators rely on nonreciprocal optical elements—Faraday rotators, magneto-optical cavities, or topological photonic crystals—to direct light sequentially between ports. Designs vary from fiber-based, waveguide-integrated, to free-space systems, with considerations for polarization independence, isolation, bandwidth, and miniaturization. These structures are essential for bi-directional optical communication, signal routing, and integrated photonic circuits.

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Article Content

(PDF) Optimized design of multiport optical circulator

This research proposes a practical multiport optical circulator design by using polarizing beam splitter cubes as spatial walk-off polarizers. The use of Porro prisms for directing light requires fewer

Optical circulator

In 1965, Ribbens reported an early form of optical circulator that utilized a Nicol prism with a Faraday rotator. With the advent of fiber and guided-wave optics, waveguide-integrable and polarization-independent optical circulators were later introduced. The concept was later extended to silicon photonic waveguide systems. In 2016, Scheucher et al. have demonstrated a fiber-integrated optical circulator whose nonreciprocal behavior originated from the chiral interaction between a single Rb atom and the co

Structure and operation principle of a six-port optical circulator for ...

In this paper, the design process of a novel three-port graphene-based circulator in terahertz (THz) and infrared frequencies is presented. This new structure consists of three 120° rotational...

The Design of a Circulator Based on Topological

Based on the aforementioned structure, we propose a circulator that consists of three types of photonic crystals, namely PC0, PC1, and PC2, as

Structure and operation principles of the proposed 4

Structure and operation principles of the proposed 4-port polarization independent optical circulator. Based on the coupled-wave theory, a holographic spatial walk

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The systems and method may include or use one or more of the various forms of optical circulator. In one arrangement, the present disclosure facilitates spatial profile estimation based on...

Multiport optical circulator by using polarizing beam splitter cubes as ...

This paper proposes a design of a multiport optical circulator by using polarizing beam splitter cubes as spatial walk-off polarizers. To show the feasibility of the design, a prototype of a six-port optical

Optical Circulator

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Figure 3.5.28 illustrates the configuration of a polarization-independent optical circulator. Similar to a polarization-independent optical isolator discussed previously, an optical circulator also uses YVO 4

Dynamically reconfigurable integrated optical circulators

In this work, to the best of our knowledge, we present the first realization of integrated optical circulators on silicon that are electrically driven and dynamically reconfig-urable. The

Optical Circulators | How it works, Application

Explore the fundamentals of Optical Circulators, their design, applications, challenges, and future prospects in optical technology.

Photonic Modal Circulator Using Temporal Refractive-Index Modulation ...

It has been demonstrated that dynamic refractive-index modulation, which breaks time-reversal symmetry, can be used to create on-chip nonreciprocal photonic devices. In order to

Optical circulator

An optical circulator is a three- or four-port optical device designed such that light entering any port exits from the next. This means that if light enters port 1 it is emitted from port 2, but if some of the emitted

Optocirculator Basics: Functionality and Applications

The optocirculator is a circulator designed specifically for optical communication. Think of it as an optical isolator but with a clever twist. While an optical isolator simply blocks signals traveling in the reverse

Versatile broadband polarization-independent optical circulators for ...

The optical circulator is a fundamental building block of photonic systems, due to its ability to route signals entering the device at various ports, as well as provide optical isolation. Fundamentally, the

Integrated TE and TM optical circulators on ultra-low-loss silicon ...

Abstract: In this paper, we present two four-port optical circulators for TE and TM modes, respectively. Exploiting the recent technological development concerning Ce:YIG pulse laser deposition on silicon

Simplified Design of Multiport Optical Circulator With Parallel ...

This letter proposes a simplified design of multiport optical circulator with parallel connection of mirror-image arranged spatial- and polarization-modules. To show the feasibility of the

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Design and Analysis of a Novel Optical Circulator Based on Photonic ...

In this paper, a novel design of a 4-port optical circulator is proposed using two-dimensional square lattice photonic crystal ring resonators. This design is suitable for photonic

Structure and operation principles of the proposed 4-port polarization ...

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