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Ultrafast All-optical Switching Devices

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Optical communications systems capable of operating at ultrafast speed and transmitting massive volumes of data will be essential pillar supporting the multimedia society of the future. To achieve such systems, it will be necessary to increase the speed of the optical demultiplexers, optical repeaters and other optical control devices making up today's electronic circuits. That will require ultrafast technologies for processing optical signals as light, without converting them to electrical signals.

A key device of such systems will be ultrafast all-optical switching devices that can control the intensity, phase or wavelength of optical signals by control light. Over the years, there were many efforts to develop all-optical switching devices using semiconductors, optical fibers, inorganic materials and various other materials. In this paper, I will introduce the most promising materials such as semiconductor multiple-quantum wells (MQW) and chalcogenide glass fibers for the realization of ultrafast all-optical switching devices.

There are two approaches to fabricate ultrafast all-optical switching devices using optical nonlinearity. One is to use resonant materials, and the other is to use non-resonant nonlinear materials.

Very recently, we have realized two types of all-optical switching devices for 1.55 μm wavelength region. One is a surface-reflection-type all-optical switching device using low-temperature-grown multiple quantum wells, and the other is a transparent-type all-optical switching devices using a chalcogenide glass fiber.

A low-temperature-grown surface-reflection all-optical switch (LOTOS) was made with 200°C-grown Be-doped InGaAs/InAlAs MQWs grown by gas source molecular beam epitaxy equipment. LOTOS is basically a saturable absorber that relies on a carrier-induced bleaching of the 2-D excitonic absorption.

The operating principle of the LOTOS is shown schematically in Fig. 1. This surface-reflection switch has an InGaAsP/InP distributed Bragg reflector (DBR) on the substrate side and a gold mirror on the other side of the InGaAs/InAlAs MQWs. The InGaAsP/InP DBR and gold mirror forms a nonlinear cavity. The thickness of the

InAlAs/InP layers is adjusted so that the two reflected lights cancel each other out by destructive interference.

Generally speaking, saturable absorption requires long recovery time due to long carrier lifetime in ordinary MQW structure. We improved the photoresponse speed by combining Be-doping with low-growth temperature. By adjusting the doping level, we can set the lifetime from 100 ps to less1 ps. We achieved a reasonable time of 1.5 ps and on/off ratio of 13 dB at a switching energy of 2 pJ as shown in Fig. 2 [1]. These performances are the highest for all-optical switching using semiconductors in longer wavelength region. We also demonstrated an all-optical demultiplexer that can handle two channels simultaneously [2].

As_2S_3-based glass has a large non-resonant third-order nonlinear coefficient and ultrafast response time of less than 100 fs. To decrease the switching power, we used a high Δn and small radius As_2S_3-based glass fiber. Laser-diode-driven switching operation is demonstrated using a nonlinear optical loop mirror (NOLM) containing a 4m-long As_2S_3-based fiber module as shown in Fig. 3. The total insertion loss was 6.3 dB and the reflection from fiber module was measured to be less than 0.4 %. Gate and signal pulses are generated by gain switching of DFB lasers and compression with a positive dispersion fiber. We measured the switching power, using an 8 ps-wide signal pulse and an 11 ps-wide gate pulse. Figure 4 shows the average power of the switched signal pulse as a function of the gate power coupled to the chalcogenide glass fiber. The π phase shift was obtained at a gate power of 0.4 W, which is the lowest value for all-optical switching using non-resonant highly nonlinear materials [3].

These two types of ultrafast all-optical switching devices are expected to be key devices of future ultrafast optical communications systems.

References

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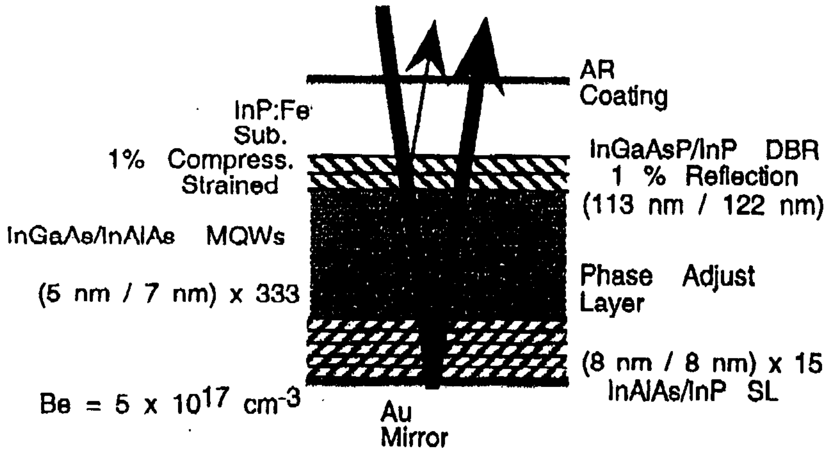

Fig. 1 **LOTOS**: Low-Temperature-Grown Surface-Reflection All-Optical switch

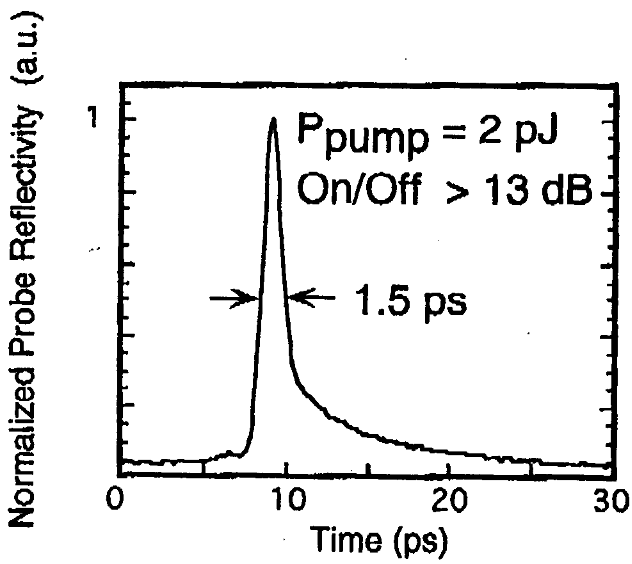

Fig. 2 Time-resolved reflectivity of LOTOS.

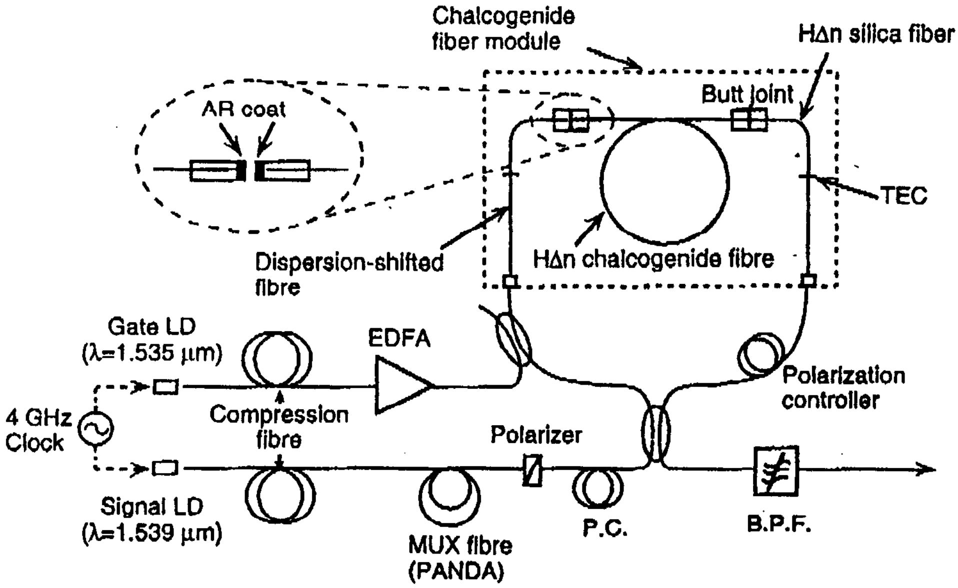

Fig. 3 All-optical switching using As_2S_3- based fiber

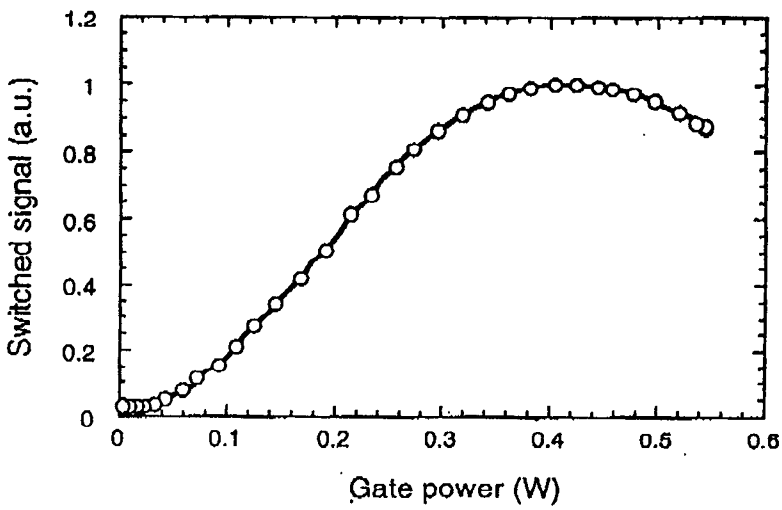

Fig. 4 Gate power vs. transmittance