Microwave performance: The small signal *s* parameters of the 180 μm common-emitter device were taken using on-wafer measurements up to 40 GHz. The current gain cutoff frequency f_t and maximum frequency of oscillation f_{max} values were determined from these measurements to be 40 GHz and

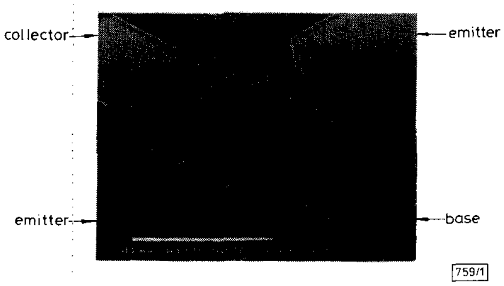

Fig. 1 *SEM picture of 180 μm emitter length HBT unit cell*

55 GHz, respectively. The small signal maximum stable gain at 15 GHz was 8·5 dB, showing suitability for Ku-band application.

The *s* parameters were then used to obtain a small-signal model of the device, and to design prematching circuits for the input port. The prematching circuit shown schematically in Fig. 2 was realised using a 0·7 mil bond wire and a chip capacitor. External tuning was used to match the impedance of the output port.

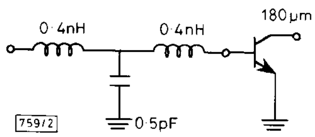

Fig. 2 *Matching circuit used for input port*

The prematched device yielded an input return loss of 20 dB at 15 GHz for high RF power levels, showing little change in the input impedance from low to high RF power levels. Several collector voltages were used to investigate optimum biasing for high output power and efficiency. With the collector biased at 10 V, a linear gain of 6 dB was obtained with up to 22 dBm input power as shown in Fig. 3. The 1 dB gain compression point was reached at 25 dBm input power where the device power-added efficiency peaked at 42% with 30 dBm output power (5·6 W/mm of emitter length power density) and 5·0 dB power gain. To our knowledge, this is the highest power and power density obtained with HBTs at 15 GHz.

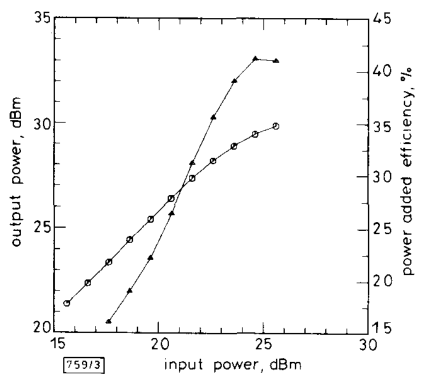

Fig. 3 *Output power characteristics of 180 μm emitter length unit cell at 15 GHz*

○ output power
△ power added efficiency

Conclusions: In conclusion, we report the first common-emitter HBT amplifier operation at Ku-band frequencies with 1 W CW output operation with 42% power-added efficiency and 10 V collector bias. The use of carbon-doping in the base layer and the design of a compact unit cell were responsible for high (5·6 W/mm of emitter length) power density operation.

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NOVEL PHOTONIC DEVICE USING NONLINEAR CORNER-BEND STRUCTURE

Indexing terms: Optical switching, Directional couplers, Nonlinear optics, Optics, Optoelectronics

A novel photonic device is proposed for optical switching by using a corner-bend waveguide structure with a Kerr-like nonlinear dielectric interface. For certain specific input signal power, the device proposed can also function as a power divider. The switching characteristics and spatial soliton propagation in the structure are discussed.

It has been well demonstrated that all-optical switching devices have the potential for applications in ultrafast signal processing and telecommunications.[1–3] It has also been proved experimentally that standard integrated optical devices can be operated in all-optical mode by using materials exhibiting intensity-dependent refractive indices.[4] Therefore, most research has been carried out on optical switching. In the past decade especially, much attention has been focused on the nonlinear directional coupler,[5,6] with which the light propagating along the waveguide can be switched by controlling its intensity. Recently, Ogusu[7] studied a structure of bent nonlinear dielectric interface. There is an inherently low power range in which no nonlinear guided modes can be supported. Moreover, as far as the design of an all-optical device is concerned, a waveguide structure is more practical compared to a single dielectric interface. Here we propose a different method for obtaining the optical switching by using a simple corner-bend structure with a Kerr-like nonlinear dielectric interface as shown in Fig. 1. For this device, we have studied its basic switching, spatial scanning, and power dividing capabilities by

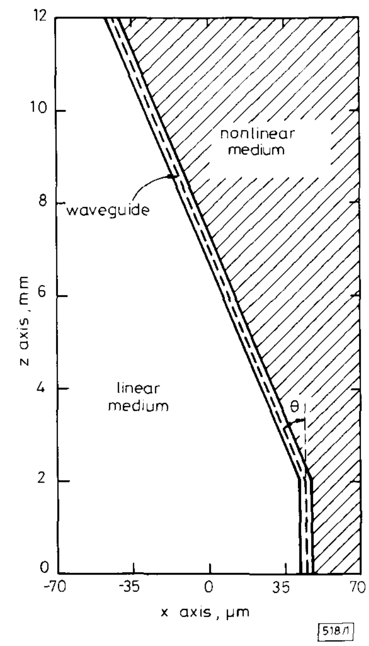

Fig. 1 *Schematic structure of proposed optical switching*
Region I: waveguide bend
Region II: power divider
Region III: scanner/switch

the beam propagation method (BPM). The numerical results show that the proposed nonlinear device will be useful for practical applications.

For simplicity and clarity, only the two-dimensional structure is considered. The device consists of a singlemode slab waveguide with a bending angle of 0·5° and a propagation length of 1 cm. The nonlinear medium lies on the right hand side of the waveguide, in which the spatial soliton can be excited. Hence, switching behaviour similar to that proposed by Ogusu[7] can be obtained by controlling the input optical power.

To study the lightwave propagation in the waveguide, the electric field of the light is assumed to be

$$E(x, z, t) = \varepsilon(x, z) \exp [j(\omega t - kz)] \tag{1}$$

where $k = \beta k_0$, k_0 is the free space wavenumber, and β is the effective refractive index. For convenience, the two-dimensional electric field is assumed to be y-independent TE-polarised, and slowly varying in amplitude. The scalar Helmholtz equation is then reduced to

$$-2jk \frac{\partial \varepsilon}{\partial z} + \frac{\partial^2 \varepsilon}{\partial x^2} + k_0^2[n^2(x, z, |\varepsilon|^2 - \beta^2)]\varepsilon = 0 \tag{2}$$

For the Kerr-like media, n^2 can be written as

$$n^2(x, z, |\varepsilon|^2) = n_L^2(x, z) + \alpha |\varepsilon|^2 \tag{3}$$

where $n_L(x, z)$ is the linear refractive index distribution of the device and α is the nonlinear coefficient. For numerical calculation the following parameters are adopted: $n_c = 2{\cdot}2885$ for the waveguide cladding, $n_s = 2{\cdot}2885$ for the substrate, $n_f = 2{\cdot}2888$ for the waveguiding film, and $\alpha = 10^{-8}\,\mathrm{m^2/V^2}$ for the nonlinear medium. The thickness of the waveguiding film is $6\,\mu$m and the free space wavelength $\lambda_0 = 0{\cdot}6328\,\mu$m. In our calculations, a 512 point transverse grid is used with a transverse sampling interval of $0{\cdot}2754\,\mu$m and a propagation step of $0{\cdot}2\,\mu$m.

To treat the proposed device generally, signals with different input power are launched into the waveguide. The input beam is deflected by an angle θ_d ($\theta_d \leq \theta$) with respect to the z axis. Fig. 2 shows the relation between the deflection angle and the normalised input power P/P_0, where $P_0 \equiv \sqrt{(\varepsilon_0/\mu_0)}/3\alpha k_0$. With the previous numerical values, P_0 is equal to $8{\cdot}91\,\mu$W/mm. Referring to Fig. 2, in the low power regime,

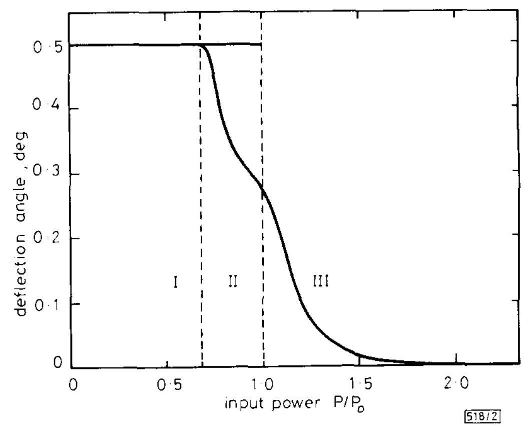

Fig. 2 *Relation between deflection angle and normalised input power*

the wave propagation along the structure is well confined along the guide, reminiscent of the behaviour obtained when the nonlinear interplay is absent, i.e. the radiation loss owing to the bending is insignificant. Consider now increasing the input signal power. When P reaches $\sim 1{\cdot}123P_0$, the wave path in the waveguide follows a smaller radius bend and the input wave excites a spatial soliton in the nonlinear medium. The solitary wave propagates along a specific direction, making an angle of 0·17° relative to the z direction of propagation. Further increase in P will decrease θ_d. This continues until θ_d reaches its saturated value; that is, the solitary wave propagates as if there were no guiding at all. To show this, the rear part of the bent waveguide was removed numerically: essentially the same results were obtained. That means, when the nonlinearity is strong enough, the presence of the waveguide has no effect on the propagation of the solitary wave and it is then reduced to the same high power limit as that of the Ogusu structure. A more interesting situation arose when the input power was $\sim P = 0{\cdot}876P_0$; the proposed device can act as a power divider as shown in Fig. 3. As can be seen from the Figure, the energy loss was trapped by a soliton-like wave, which propagates nearly adiabatically with a small deviation angle. It is noted that the two branches within the dashed lines represent the presence of a power divider. It is clearly demonstrated that an optical switching capability, which is similar to the results achieved by Ogusu, is obtained. Moreover, the capability of some other applications in the 'middle range' of switching characteristics, such as spatial scanning and power dividing, was also demonstrated based on the selected input power. The maximum scanning sensitivity, defined as the slope of the curve of deflection angle against the input power as shown in Fig. 2, is about 0·92° per unit normalised power.

In conclusion, we have proposed a novel photonic device by using a simple nonlinear corner-bend structure. Three different operating situations based on the input optical modal power can be obtained. At the low power range, the wave evolves just as that in the linear waveguide bend. At higher powever level, controlling of the input power intensity leads to

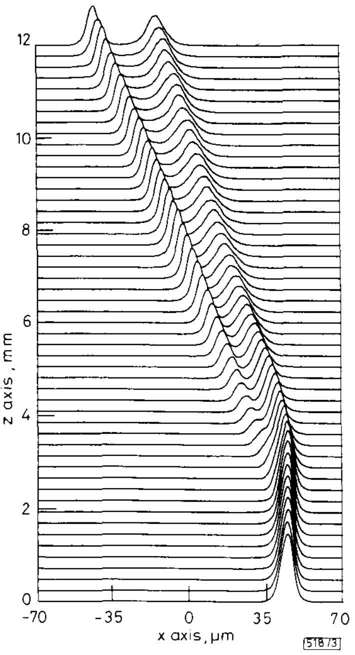

Fig. 3 *Field evolution along direction of propagation for $P = 0{\cdot}876P_0$*

a change in the propagation direction, which is a spatial scanner. With the range of input power properly selected, a power divider can be obtained. These characteristics are potentially useful for applications in all-optical signal processing and telecommunications.

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TUNNEL DIODE WITH ASYMMETRIC SPACER LAYERS FOR USE AS MICROWAVE DETECTOR

Indexing terms: Tunnel diodes, Diodes, Semiconductor devices and materials

A novel single-barrier, intraband tunnel diodes with asymmetric spacer layers has been designed and fabricated. The structural asymmetry leads to asymmetric current-voltage characteristics and makes the diodes suitable for use as zero-bias microwave detectors. The voltage sensitivity as 9·375 GHz shows a weak temperature dependence (typically less than 1 dB variation over $-40°-+80°C$, compared with 3 dB for a zero-bias Schottky diode). The maximum microwave power handling is also superior to a germanium back diode (1 dB rolloff typically at +10 dBm compared with −10 dBm for the Ge back diode) and similar to a zero-bias Schottky diode.

There is at present much interest in vertical tunnel structures made from material systems such as GaAs/AlGaAs and InAs/AlSb. The focus of this interest has tended to be double barrier resonant tunnelling diodes, because of their ability to produce power with a fundamental frequency in the submillimetre regime (frequencies as high as 712 GHz have been demonstrated).[1] However, the power levels produced are modest, and practical applications of such devices seem a long way off. The use of tunnel structures as selfoscillating mixers or as detectors does however seem a more promising line of research in the shorter term, and indeed we have previously reported the use of multilayer GaAs/AlAs tunnel diodes as microwave detectors at X band.[2] These diodes exhibited some kinks in their transfer function (voltage out against microwave power in) and for conventional purposes this is usually undesirable. The structure in the transfer function corresponds to the structure in the DC I–V characteristic and arises from the resonant tunnelling process. To achieve a monotonic transfer function, we have designed a novel single barrier structure with asymmetric, undoped spacer layers, which we refer to as an ASPAT (asymmetric spacer-region tunnel) diode. The conduction band profile of a typical device (referred to henceforth as DB1220) is shown in Fig. 1. The profile was obtained by solving the Poisson equation using a finite temperature Thomas–Fermi approximation and Fermi statistics.

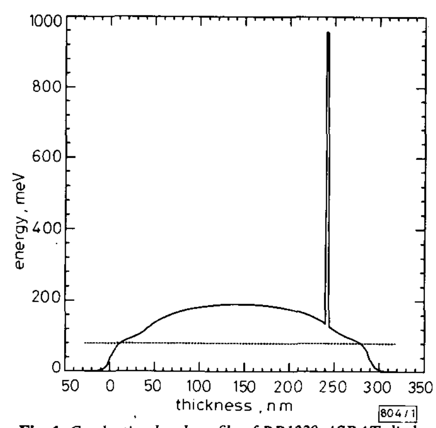

Fig. 1 *Conduction band profile of DB1220 ASPAT diode at 300 K and zero bias, calculated by solving Poisson equation*

– – – – chemical potential

Because our aim is to produce a zero-bias detector (which is essentially a rectifier of the microwave signal), it is important to have an asymmetric I–V characteristic. For our earlier multilayer structures, this was achieved by tailoring the thicknesses of the barriers and wells. Here we achieve I–V asymmetry by designing a doping asymmetry into the device: this is the purpose of having one long and one short spacer region. The ASPAT diodes were grown by MBE on (100) n^+ GaAs