Nonlinearity and Power Handling Characterization of an Optically Reconfigurable Microwave Switch

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***Abstract*—This paper presents a highly linear optically reconfigurable microwave switch with high power handling ability. A silicon superstrate with bottom illumination is employed. A transparent substrate is used and two different microstrip gap distances are characterized by two-tone nonlinearity measurement with different tone spacings and optical powers. A maximum third order intercept point referred to input power of +78.5dBm has been obtained and the maximum microwave power tested was over 30W per tone close to 2 GHz. Thermal imaging has been used to observe the device hot-spots as a function of RF power.**

***Index Terms*— Nonlinearity characterization, Microwave device, Photoconducting switches**

I. Introduction

Reconfigurable circuitry reduces system size and provides the possibilities of frequency and phase tuning. Mature reconfiguration technologies are based on Varactor diodes, PIN diodes and Radio-Frequency MicroElectroMechanical Systems (RF MEMS) [1]. All these approaches require DC biasing networks which as systems become more complex and move to higher frequencies will being to impact on system performance. Diodes will also produce non-linear distortion, though there are approaches to overcome this such as placing them at field nulls. Photoconductive tunable devices show potential to solve all these problem, with the drawback of requiring optical illumination of a semiconductor. However, over the past 20 years there has been significant improvement in laser and LED performance to the point where low cost, high power LED arrays are available and laser arrays using Vertical Cavity Surface Emitting Lasers (VCSELs) are becoming available [2]. This paper explores the achievable power levels and performs non-linear characterisation of a 2GHz switch with the aim of establishing the upper limits of performance for this technology.

The concept of photoconductive tunable microwave circuits has been described in [3,4]. When illuminated by photon energy above the band gap, a semiconductor becomes electrically conductive. An electron-hole plasma region is created [3] and this can be used to reconfigure microwave circuits and antennas with the functionality depending on where the semiconductor is placed and how it is illuminated.

This paper will firstly present the measured linear S-parameter results for a bottom illuminated superstrate microstrip gapline switch. Two tone non-linearity measurement is then performed and the Third Order Intercept Point (IP3) is measured. Finally, thermal imaging data results are shown which will in future be used to explore the complex Multiphysics process of simultaneously high power RF and optical illumination of the semiconductor. This will allow us to understand the fundamental limits of non-linearity in this system that contains no PN junctions.

II. Fabrication and Structure Design

Fig. 1 shows a schematic diagram of the structure with a top view image inset. Fused silica (ε=3.5) is used as an optically transparent, low loss substrate and the silicon is held in place by a Perspex bar with heat insulation provided by a quartz bar. In future, high temperature conductive glues could be used to hold the silicon in place.

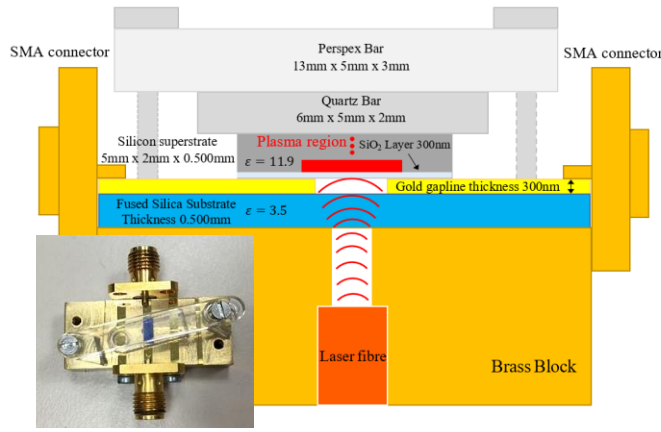

Fig. 1. Schematic side view a microstrip line on fused silica. Inset top view picture.

The silicon superstrate is 5mm x 2mm x 0.5mm (ε=11.9), lightly n-type doped with <100> orientation and resistivity $>$ $10k\Omega$.cm. It is passivated with 300nm thick silicon dioxide to prevent a Schottky contact forming between the gold and silicon surface. A fibre coupled continuous wave laser diode (Roithner Lasertechnik) is used with a wavelength of 980nm, chosen to optimise carrier generation efficiency. Near InfraRed (NIR) light is delivered through a drilled hole and the fused silica substrate which creates an electron-hole plasma region. These generated excess carriers have highest density with highest conductivity close to the surface in contact with microstrip gap. The plasma tail with lower conductivity diffuses within the silicon further away from the high microwave field region in the gap and the fused silica substrate, which can reduce losses compared with top illumination [5].

III. Measurement

Fig. 2 shows the measured S_{21} for two samples of different geometries with varying laser powers. Sample 1 has a 0.4mm gap, 1.0mm linewidth and a 1mm diameter hole in the brass block. Sample 2 has 0.1mm gap, 1.6mm linewidth and a 2mm diameter hole in the brass block. In the no-light case (OFF), 20dB isolation is observed for Sample 1 and a rapid rise in S_{21}

can be observed at 8mW illumination power with saturation occurring around 35mW. The insertion loss at 2GHz is 1.11 dB for Sample 1 and 2.35 dB for Sample 2 at 175mW optical power. It is believed that the increased insertion loss for Sample 2 is caused by the 2mm diameter hole reducing the light focusing and thus reducing the intensity. The rapid roll off in S21 at low frequency is caused by the silica passivation layer acting as a series capacitor.

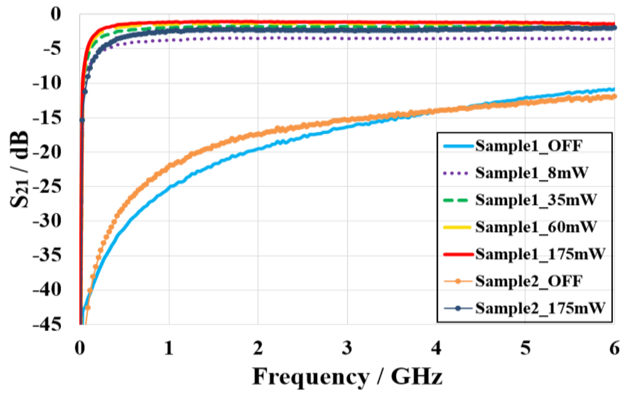

Fig. 2. Measured S_{21} magnitude for Sample 1 (0.4mm gap and 1.0mm linewidth) and Sample 2 (0.1mm gap and 1.6mm linewidth) at varying laser power levels.

IV. Non-Linear and Power Handling Measurement

Large signal characterisation in the presence of a two-tone signal is performed to investigate the non-linear behaviour of the switch, in terms of intermodulation products, and its high power handling ability. The frequencies of these two tones are varied from (i) 1.999 GHz and 2.001GHz, (ii) 2.000GHz and 2.001GHz and (iii) 2.0005GHz and 2.001GHz to give spacings of 200MHz, 100MHz and 50MHz respectively. The illumination power was varied from 0mW, 35mW and 175mW for each Sample 1 and 2. Fig. 3 shows the two-tone non-linearity measurement set up. The two-tone signals were generated by two synchronised signal generators and combined after two linear amplifiers. This approach was taken since the use of a single driver with a two-tone generator at its input may result in the observation of the driver non-linear behaviour rather than that of the microwave switch.

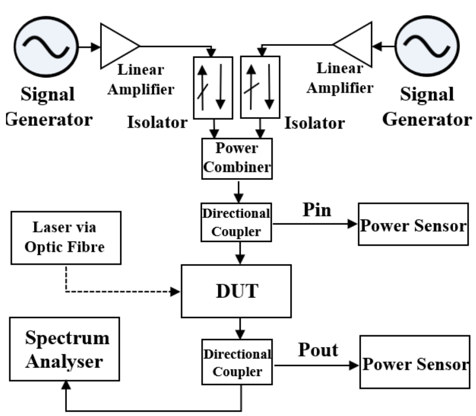

Fig. 3. Non-linearity measurement schematic diagram

Power meters were used to measure input and output power levels at the terminals of the microwave switch. The results are measured on a Rohde & Schwarz spectrum analyser and are shown in Fig. 4 which is raw data prior to the use of offsets needed to compensate for the presence of attenuators in the set up. An initial test was carried out on a 1.1mm wide through line with 50Ohm characteristic impedance to examine the inherent nonlinearity of the set up with results shown in Fig. 4(a). It can be seen that at a P_{in} of +47.85 dBm (~61W) no Third Order InterModulation products (IM_3) were observed.

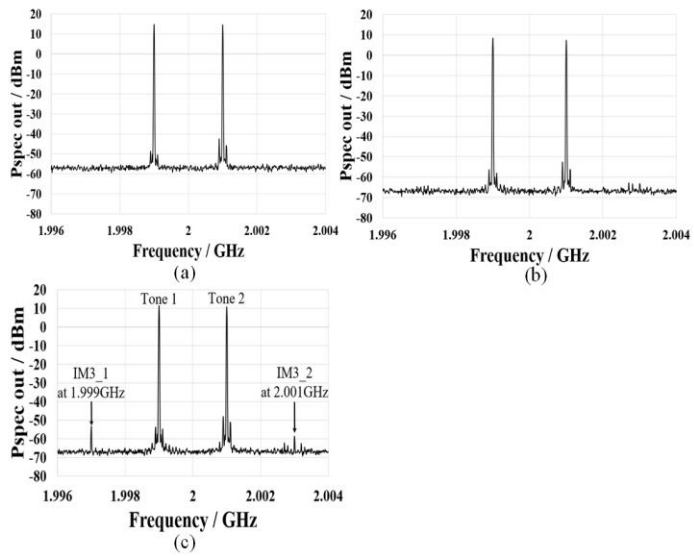

Fig. 4. Measured output power spectra (a) P_{in} = +47.85 dBm in a 1.1mm linewidth microstrip linewidth, (b) P_{in} = +42.77 dBm in Sample 1 (0.4mm gap and 1.0mm linewidth) with 200MHz tone spacing at 175mW optical power, (c) P_{in} = +46.22 dBm in Sample 1 with 200MHz tone spacing at 175mW optical power.

Fig. 4(b) shows the case for Sample 1 (0.4mm gap and 1.0mm linewidth) with 200MHz tone spacing at 175mW optical power and no obvious IM_3 can be determined as input power increased up to +42.77 dBm (~10W per tone). Fig. 4(c) shows that an asymmetric IM_3 pair is observed at 1.997GHz and 2.003GHz when it is powered up to +46.22 dBm (~21W per tone). The reason for this is the minor difference between fundamental tones signals which causes an imbalanced IM_3 output. At this power level, no material melting or insertion loss deterioration was observed which suggests a very robust clamp fixture.

The data for each sample is then plotted as shown in Fig. 5 with P_{out} v P_{in} in order to determine the Third Order Intercept Point referred to Input Power (IIP3) and this is estimated to be +77dBm for Sample 1 with tone spacing of 200MHz at 175mW optical power.

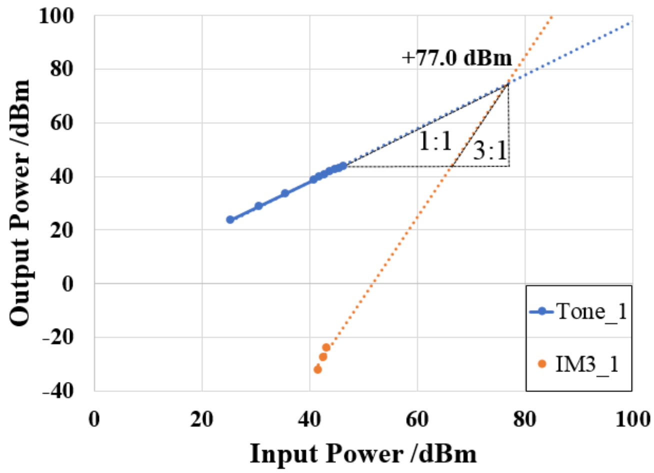

Fig. 5. Extrapolated IIP3 value for Sample 1 with tone spacing of 200MHz at 175mW optical power

All the IIP3 data is then collated and shown in Fig. 6. There are some interesting trends observed, in particular that the IIP3 does not improve significantly beyond the 35mW point and in some cases, it decreases. The best-case frequency spacing is 100MHz for both Sample 1 and 2 at 35mW with a best-case IIP3 of +78.5dBm. In future work we will develop lumped element non-linear models which will enable us to understand the various trends observed here.

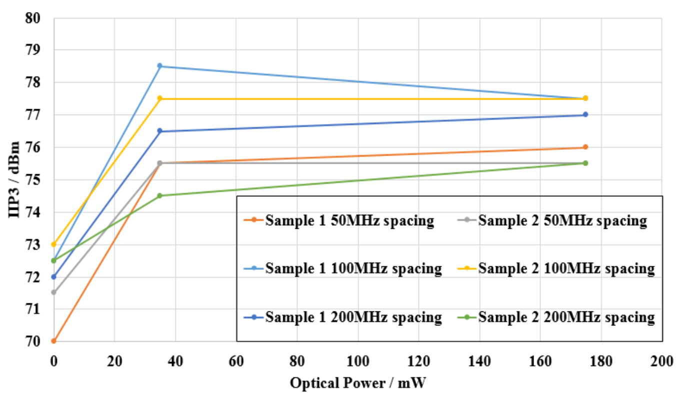

Fig. 6. IIP3 for different tone spacings and optical powers for Sample 1 (0.4mm gap and 1.0mm linewidth) and Sample 2 (0.1mm gap and 1.6mm linewidth).

Finally, we have used a thermal imaging camera to observe the sample temperature at different RF power levels. We plan to use COMSOL Finite Element modelling, including semiconductors physics, RF and Optical heating to understand the fundamental limitations on the non-linearity in these photoconductive switches. Fig. 7 shows three images taken during the measurement using a NIR sensor camera from FLIR. As expected the whole brass fixture becomes hot and the central quartz bar acts to thermally isolate the central region. Heat is seen to conduct around the quartz giving rise to two hot spots on either side.

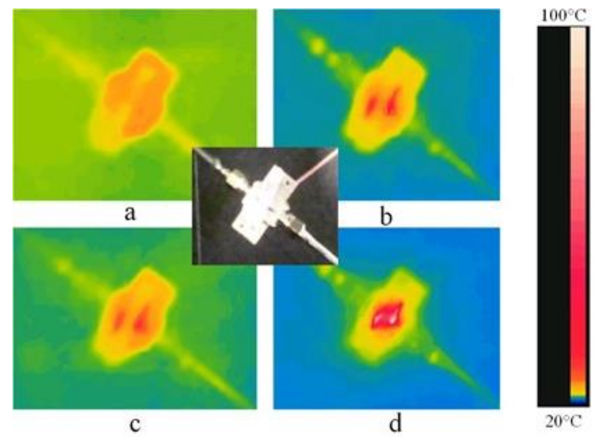

Fig. 7. Thermal images of Sample 1 at 200MHz tone spacing and 175mW optical power with RF input power at (a) 18.53dBm, (b) 36.69 dBm, (c) 43.86 dBm, (d) 46.89 dBm. Inset optical image of the device.

V. Conclusion

This paper has presented a bottom illuminated photoconductive reconfigurable microwave switch with a minimum insertion loss of 1.11 dB at 2GHz and an isolation of 20dB. There was no observable IM_3 in the spectrum when input power has been raised up to nearly 20W in a two-tone measurement. With further power increased, third order distortion appeared and the best-case IIP3 was +78.5dBm. Optimisation of the microstrip gap geometry and collimation of laser will further improve the switch performance. In future we plan to characterise these devices at higher frequencies that will be relevant for 5G applications. Thermal imaging has been used to observe the device hot spots and multiphysics finite element modelling will be used to understand non-linear effects in these devices.

References

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