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A MICROGAP SURGE ABSORBER FABRICATED USING CONVENTIONAL SEMICONDUCTOR TECHNOLOGY

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Abstract: A new type microgap surge absorber fabricated by only semiconductor technique has in it a special structure silicon chip which forms microgaps for gas discharge with electrodes, and has advantages such as small size, low cost, suitability for mass production besides the desirable characteristics that common microgap surge absorbers have. Applications of this absorber in communication facilities are discussed.

Key words: surge absorber, gas discharge, microgap, semiconductor technology
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INTRODUCTION

Various types of surge absorbers to protect various low-voltage electrical circuits from transient overvoltage include: (1) gas discharge tube (gaseous gap), (2) varistors, (3) semiconductor TVS (transient voltage suppressor). Each type has its advantages and disadvantages. Gaseous gap type arrestors have big surge current capacity, low residual voltage. But their electrostatic capacitance is about 10 pF and response time is 1 - 3μs. Varistors have quick response and bigger surge current capacity, but high residual voltage. The semiconductor TVS's have quick response and low residual voltage, but small surge current capacity and large junction capacitance. The microgap surge absorber (Ando, 1985; Tachibana, 1980) is an application of gaseous discharge along a resistive surface. The microgap supplies initial electrons and triggers a surface streamer to build up a glow discharge, so a radioactive isotope is not necessary to supply initial electrons. The microgap surge absorber has highly desirable characteristics such as quick response (< 0.5 μs), small capacitance (< 1 pF), etc.

Fig.1 shows a cross section of the microgap surge absorber with a single microgap (Ando, 1985). A laser beam was used to remove a narrow ring from a thin semiconducting film of SnO_2 coated on a ceramic tube. The width of the microgap is equal to the width of the film removed. Both ends of the ceramic tube were capped by metal electrodes with leadwires and the entire assembly was enclosed in a glass envelope filled with inert gasses. The disadvantages of the absorber are quite apparent. The process of manufacture is too complex. Fairly low efficiency arises when the film is removed by a laser beam. The cost of the manufacture is high and the surge absorber is a bit too large.

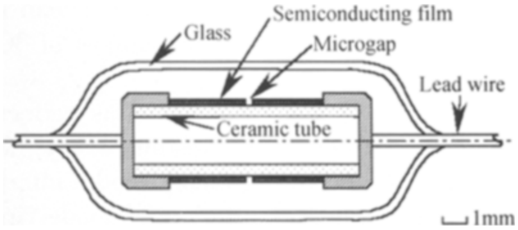


Fig.1 Cross section of the microgap surge absorber with a single microgap

This paper describes a fabrication process in which only semiconductor technique is used to make a new type of microgap surge absorber with microgap consisting of semiconducting silicon and metal electrodes. Such microgap surge absorber has advantages such as small size, low cost of fabrication, suitability for mass production, besides the desirable characteristics that common microgap surge absorbers have. Studies have been made on the potential the application of the new type of microgap surge absorber in communications facilities.

STRUCTURE AND PRINCIPLE

1. Structure

Fig.2 shows a cross section of the new type of microgap surge absorber. Its package is in the form of a glass DO-41 (or DO-35) generally used for semiconductor diodes such as zener diodes. The two ends A and B of the electrodes are directly used as discharge electrodes. The microgaps are composed of the edge of the Si chip and the ends A and B. The glass tube was filled with inert gasses.

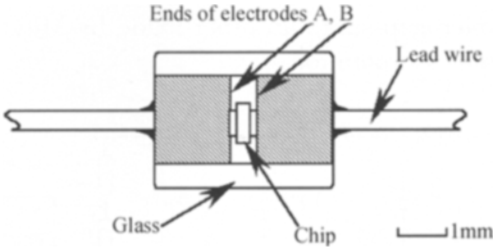


Fig.2 Cross section of the new type microgap surge absorber with double microgaps (DO-41)

Fig.3 shows the structure of the key part-Si chip-of the new type microgap surge absorber. Fig.3(a) shows the structure of the Si chip for double microgaps. The edges of N_1^+ layer and N_2^+ layer in the chip form two microgaps with the two ends A and B of the electrodes. The width of the microgaps is the height of the mesas d. The structure of the chip is symmetric, so the forward and reversed spark overvoltage (V_s) is almost the same. Such a chip is used when V_s is relatively high. Fig.3(b) shows the structure of the Si chip for a single microgap. The microgap is formed by the edge of N^+ layer in the chip and the end section of an electrode. The chip with such a structure is used when Vs is relatively low.

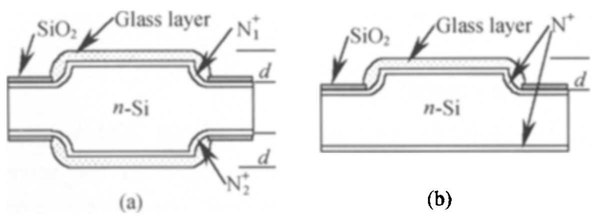


Fig.3 Structures of Si chip

(a) double microgap chip; (b) single microgap chip

2. Principle

When the voltage on the two ends of the new type microgap surge absorber increases to a certain extent, a strong electric field is formed near the microgaps and discharge begins (Ando, 1985; Boylett, 1971). The gases near the microgaps are ionized. Now discharge current flows through the substrate of the Si chip. With the increase of discharge current, the voltage drop on the chip increases. The zone of the ionized gasses extends. The discharge current flows to the other electrode through the zone of ionized gasses. When current increases to a certain level, the discharge in the device changes from glow discharge to arc discharge.

As initial electrons of discharge are provided by the strong electric field near the microgaps, the response of the new type of microgap surge absorber is faster than that of the common arrestors (gaseous gap). When discharge reaches fairly high level, instead of flowing through the semiconductor substrate, almost all current flows through the ionized gas, which makes the new type of microgap surge absorber have large surge current capacity. Because of the functions of the Si chip mentioned above, the Si substrate resistivity (ρ) should be selected suitably. If ρ is too high, the microgaps will lose the function of providing initial electrons. If ρ is too low, relatively strong current will flow through and ruin the substrate.

FABRICATION

Two chips shown in Fig.3 (of a single microgap chip and two-microgap chip with various heights of mesa d) were fabricated. Used in this study were 270 μm thick, 10 to 20 $\Omega\cdot$cm n-type silicon wafers. The processing steps for fabricating the chips were as follows. The wafers were first cleaned and degreased and double silicon dioxide layers of about 1 μm were then grown on them thermally. A double sides (double microgaps) or single side (single microgap) zone, except windows, was cut in the SiO_2 film using conventional photoresist techniques. Using the windows of SiO_2 as a mask, the wafers were isotropically etched to form the mesas. The mask was removed in 10 : 1, H_2O : HF. Double N^+ layers of about 10 μm were phosphorus-diffused at 1100 ℃. Following this step, other SiO_2 layers of about 0.7 μm were grown, and photoresist was used to cut the SiO_2 on mesas. Powdered glass layers of about 30 μm were plated by electrophoresis on the mesas. After the powdered glass layers were fired at 810 ℃, they were changed into glass layers of about 10 μm. Wafers were scribed by a diamond-impregnated saw blade to form the chips (400 μm), then the chips were cleaned for sealing.

The next process, the sealing of the new type of microgap surge absorber, was done at above 600 ℃ in a glass-sealing machine made by AYUMI Industry Co., Ltd. The sealing program is listed in Table 1.

Table 1 Glass sealing program

Step	Time (s)	Switch state*	Temperature (℃)	Notes
1	60	PV		Pumping
2	15	V1		Filling
3	240	PV, H	550	Heating
4	80	PV, H	550	Constant Temp. Cleaning
5	300	PV	300	Cooling
6	30	V1, H	300	Filling
7	100	H	670	Heating
8	60	H	670	Constant Temp. Sealing
9	5	V2		Pressurizing
10	800			Cooling
11	2	END		End

* V1, V2: filling valves, H: heater, PV: pumping valve.

Based on its spark overvoltage, the new type absorber can be sealed by various chips (with different width and number of microgaps), and different gases (Ne + Ar, Ne, Ar, Ar + H_2, N_2 …) under gaseous pressure (10^4 Pa to 7×10^6 Pa). For example, the new type of absorber with V_s of about 300 V can be sealed by 20 μm × 2 double microgap chips and pure Ar under pressure of 5×10^4 Pa.

EXPERIMENTAL RESULTS

1. Surge absorption characteristics

The circuit shown in Fig.4 was used to determine the surge absorption characteristics of various new type microgap surge absorbers. The voltage pulse produced by the circuit was 10 / 700 μs and its peak voltage (V_p) was 1000 V. The original waveform of the voltage pulse and the absorption waveforms of typical samples are shown in Fig.5. Sample A was for V_s of about 300 V, Ar + 1% H_2 (mixed gases) and 20 μm × 2 double microgap chip. Sample B was for V_s of about 300 V, Ar + 1% H_2 (mixed gases) and 30 μm single microgap chip. Their package was DO-41. Their pulse spark overvoltage was respectively about 370 V and 450 V. The characteristics mentioned were similar to those of DSS type microgap surge absorber made by Mits bishi Materials Corporation.

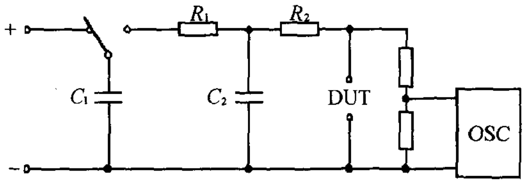


Fig.4 Schematic diagram of circuit for surge absorption characteristics, OSC is HP-54503A, circuit constants are R_1 = 15 Ω, R_2 = 25 Ω, C_1 = 20 μF, C_2 = 0.2 μF

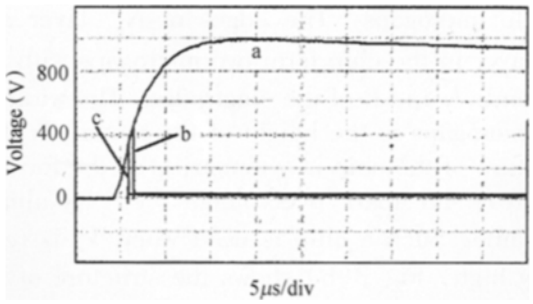


Fig.5 Surge absorption characteristics
(a) original waveform; (b) sample A;
(c) sample B

2. Surge current capacity

The sample was for V_s of about 300 V; and DO-35, DO-41 package were used in the surge current capacity test. The test conditions were 8/20 μs standard surge current for specified current applied 3 times at intervals of 5 min. Peak surge current (I_p) 200 A was chosen for the DO-35 samples while I_p 1500 A was chosen for DO-41. Application of surge current to the samples did not result in cracks or failures. The V_s of the samples before and after the test is shown in Table 2.

Table 2 V_s of samples before/after applying surge current

V_s(V) (DO-35)		V_s(V) (DO-41)	
Before test	After test	Before test	After test
295/297	298/279	338/319	312/294
272/268	279/279	309/305	327/279
285/294	306/294	320/301	251/272
294/278	287/289	333/323	315/304
279/287	305/284	302/316	290/319
		285/293	307/305

Obviously, the surge current capacity of the absorbers with DO-35 package must not be lower than 200 A while that of the absorbers with DO-41 package must not be lower than 1500 A.

3. Electrostatic capacitance and Insulation resistance

For high frequency and high resistance applications the new type of microgap surge absorber should have electrostatic capacitance < 1 pF and insulation resistance > 100 MΩ. The electrostatic capacitance of various samples tested under conditions of 1 kHz, 6 V are given in Table 3.

Table 3 Electrostatic capacitance

Package	DO-35	DO-35	DO-41	DO-41
Chip	Single microgap	Double microgaps	Single microgap	Double microgaps
Co(pF)	~0.7	~0.4	~0.8	~0.5

Table 4 On the insulation resistance of the samples.

Table 4 Insulation resistance

Samples	DO-35 V_s ~ 150V	DO-35 V_s ~ 200V	DO-41 V_s ~ 300V	DO-41 V_s ~ 800V
Testing voltage	50 V	100 V	100 V	250 V
IR(Ω)	$> 10^{10}$	$> 10^{10}$	$> 10^{10}$	$> 10^{10}$

4. The distribution of spark overvoltage

The V_s was measured in randomly chosen DO-41 samples sealed by 20 μm × 2 double microgap chips and Ar + 1% H_2 (mixed gases), at pressure of 5×10^4 Pa. The distribution of spark overvoltage is shown in Fig.6. The spark overvoltage of more than 89 % of the selected samples was 300 V ± 10 %. The Vs average was about 298 V, standard deviation of 27.1. The Vs maximum was 365 V, minimum was 188 V. The main reason why the samples have about 200 V is that a short of one of the double microgaps results from the sealing. Thus, the structure of double microgaps turns into that of a single microgap. The samples with V_s of about 300 V had the difference between forward and reversed spark overvoltage $\Delta V_s(|V_{s+} - V_{s-}|)$ and averaged 13.5 V.

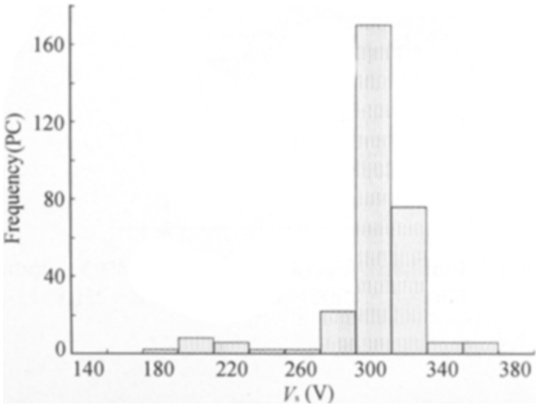


Fig.6 Distribution of spark overvoltage

APPLICATION

There are many applications for the new type microgap surge absorber. It protects telephones, modems, faxes, PBX, and other communication equipment from surges, and audio equipment (such as those inside an automobile) from a surge or electrostatic discharge from antenna. The absorbers also protect the semiconductor devices inside color TV's and CRT displays. Various electronic appliances such as: boilers, gas equipment, microwave ovens, and washing machines that need to be grounded can also be protected.

In the above applications, though the new type of microgap surge absorber has fairly fast response, it has a much slower response compared with semiconductor devices. By combining the new type of microgap surge absorber with TVS, varistor and other such devices, they are likely to respond much more quickly and have large current capacity. For example, in protection of telephones from lightning, if a new type microgap surge absorber with V_s of about 250 V is paralleled to a telephone. When the applied standard voltage pulse (10/700 μs, $V_p = 4000$ V) is between Tip and Ring, damage is often done to the parts in the telephone. If the circuit shown in Fig.7 is put into the telephone, reliable anti-lightning function is reached. The output voltage waveform and the current curve through the varistor Z are shown in Fig. 8 when voltage pulse of 10/700 μs, $V_p = 1000$ V is applied to the circuit in Fig.7.

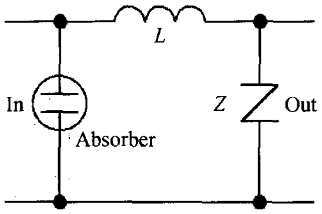
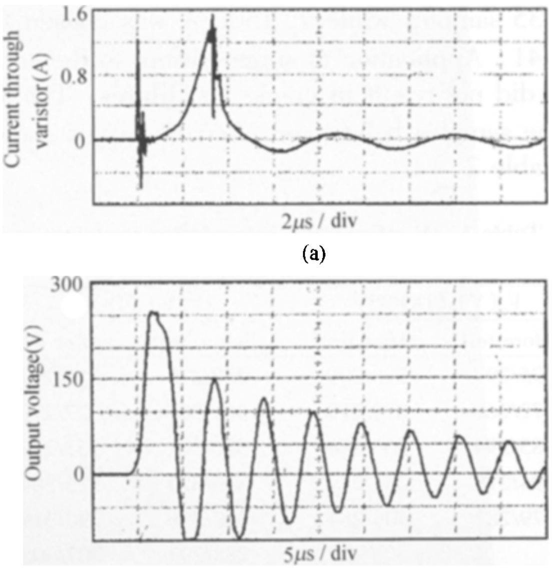


Fig.7 Combined circuit of absorber (250V), inductance L (1mH) and varistor Z (250V)

CONCLUSIONS

The new structure microgap surge absorber uses semiconductor techniques in all the fabrication processes, and had been shown to have big surge current capacity, quick response, and high insulation resistance. It can be widely used in different applications. This method of fabrication is suitable for the processing of axial package as well as for the processing of surface mount package such as MiniMELF.



(a)

(b)

Fig.8 Curves of current through varistor and output voltage in the circuit shown in Fig.7
(a) current curve through varistor
(b) output voltage waveform

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