STABLE MAPPING CLASS GROUPS
OF 4-MANIFOLDS WITH BOUNDARY

OSAMU SAEKI

Abstract. We give a complete algebraic description of the mapping class
groups of compact simply connected 4-manifolds with boundary up to con-
nected sum with copies of $S^2 \times S^2$.

1. Introduction

It has been shown in [15] that two orientation preserving homeomorphisms of
a closed simply connected 4-manifold are homotopic if and only if the induced
automorphisms on the second homology group coincide with each other (see also
[4, §5]). Using this, Quinn [15] has shown that two homeomorphisms inducing
the same automorphism on the second homology group are actually topologically
isotopic (see also [13]). Quinn has also shown that two diffeomorphisms inducing
the same automorphism are smoothly isotopic after the connected sum with the
identity diffeomorphism of some copies of $S^2 \times S^2$. In this paper we give a similar
smooth stable isotopy criterion for the case where the simply connected 4-manifold
has nonempty connected boundary.

Let $M$ be a compact 1-connected 4-manifold with nonempty connected bound-
ary. In this paper we first give an algebraic criterion for two diffeomorphisms of
$M$ to be stably isotopic (see §2), where two diffeomorphisms $h_0$ and $h_1$ of $M$ which
are the identity on the boundary are stably isotopic relative to boundary if $h_0 \# k(id)$
and $h_1 \# k(id)$ are smoothly isotopic relative to boundary as diffeomorphisms of
$M \# k(S^2 \times S^2)$ for some $k \geq 0$. We will see that certain homomorphisms
$$H_2(M, \partial M; \mathbb{Z}) \to H_2(M; \mathbb{Z}),$$
called variation maps, associated with such diffeomorphisms play an essential role.

Then in §3 we introduce the notion of the stable mapping class group of $M$
and give its complete algebraic description using the result of §2. The algebraic
objects that play an important role here are homomorphisms, called variational
homomorphisms, $H_2(M, \partial M; \mathbb{Z}) \to H_2(M; \mathbb{Z})$ which are defined to be abstract
homomorphisms satisfying certain algebraic conditions. We will see that the set of
variational homomorphisms form a group with respect to a certain multiplication.
The main content of §3 is a construction of a diffeomorphism which realizes a given variational homomorphism.

In §4 we study the relationship between the group of variational homomorphisms and the group of isometries of $H_2(M)$ endowed with the intersection form, which will be used in §5.

In §5 we consider the stable mapping class group of boundary-free diffeomorphisms of 4-manifolds whose boundaries are certain spherical 3-manifolds.

Throughout the paper, we work in the smooth category unless otherwise specified. All the homology and cohomology groups are with integer coefficients unless otherwise indicated. We use the symbol “$\cong$” to denote a diffeomorphism between smooth manifolds or an appropriate isomorphism between algebraic objects.

The author would like to thank the referee for drawing his attention to Kreck’s paper [10]. He also would like to thank the people at IRMA, Strasbourg, for their hospitality during the preparation of the manuscript.

2. Isotopy of 1-connected 4-manifolds with boundary

Let $M$ be a compact 1-connected 4-manifold with nonempty connected boundary. We first define the variation map associated with a diffeomorphism of $M$, which will play an important role throughout the paper.

**Definition 2.1.** Let $h : M \to M$ be a diffeomorphism which is the identity on the boundary. We define the variation map $\Delta_h : H_2(M, \partial M) \to H_2(M)$ as follows. For a homology class $\gamma \in H_2(M, \partial M)$, take a 2-cycle $(D, \partial D)$ in $(M, \partial M)$ representing $\gamma$. Then $D \cup (-h(D))$ is a 2-cycle in $M$ and we define $\Delta_h(\gamma)$ to be the class represented by $D \cup (-h(D))$. Note that this does not depend on the choice of $(D, \partial D)$ and that $\Delta_h$ is a homomorphism. See also [8].

Note that if two diffeomorphisms of $M$ which are the identity on the boundary are isotopic relative to boundary, then their variation maps coincide with each other. The main result of this section is that the converse is also true “stably” as follows.

**Theorem 2.2.** Let $M$ be a compact 1-connected 4-manifold with nonempty connected boundary. Suppose that $h_0$ and $h_1 : M \to M$ are two diffeomorphisms with $h_0|\partial M = h_1|\partial M$ being the identity map. Then $h_0$ and $h_1$ are stably isotopic relative to boundary if and only if $\Delta_{h_0} = \Delta_{h_1} : H_2(M, \partial M) \to H_2(M)$.

**Proof.** In the following, for an integer $k \geq 0$, $M_k$ will denote the 4-manifold $M_k(S^2 \times S^2)$.

If $h_0$ and $h_1$ are stably isotopic relative to boundary, then it is easy to see that their variation maps coincide with each other, since on the direct summand of $H_2(M_k, \partial M_k)$ corresponding to $H_2(S^2 \times S^2)$, the variation maps of $h_j, h_k(id)$, $j = 0, 1$, are the zero homomorphisms.

In order to prove the converse, let us consider the following construction, which is called an open book construction (see [8]). For a diffeomorphism $h : M \to M$ which is the identity on the boundary, let $L_h$ be the 5-dimensional manifold with boundary obtained from $M \times [0, 1]$ by identifying $M \times \{1\}$ with $M \times \{0\}$ using $h : M \times \{1\} \to M \times \{0\}$. Note that $\partial L_h$ is canonically diffeomorphic to $\partial M \times S^1$.

Then, let $N_h$ be the closed 5-dimensional manifold obtained by attaching $\partial M \times D^2$ to $L_h$ along the boundary. Note that $N_h$ is 1-connected and that $M$ is naturally identified with $M \times \{0\} \subset N_h$. 

License or copyright restrictions may apply to redistribution; see http://www.ams.org/journal-terms-of-use
Then, by an argument similar to that in [9 §2], we easily obtain the following.

**Lemma 2.3.** A diffeomorphism $h : M \to M$ which is the identity on the boundary is pseudo-isotopic to the identity relative to boundary if and only if $N_h$ bounds a compact 1-connected 6-dimensional manifold $W$ such that $\pi_j(W, M) = 0$ for all $j$.

We also have the following.

**Lemma 2.4.** Let $h : M \to M$ be a diffeomorphism which is the identity on the boundary. Then we have the following exact sequence:

$$0 \to H_3(N_h) \to H_2(M, \partial M) \xrightarrow{\Delta_h} H_2(M) \to H_2(N_h) \to 0.$$  

**Proof.** Consider the exact sequence for the pair $(N_h, M)$:

$$(2.1) \quad 0 \to H_3(N_h) \to H_3(N_h, M) \xrightarrow{\partial} H_2(M) \to H_2(N_h) \to H_2(N_h, M).$$

Let $\tilde{M} \cong M \times [0, 1]$ be a normal 1-disk bundle neighborhood of $M$ in $N_h$. Note that the closure of $N_h \setminus \tilde{M}$ is again diffeomorphic to $M \times [0, 1]$. Hence, by excision together with Poincaré-Lefschetz duality, we have

$$H_i(N_h, M) \cong H_i(N_h, \tilde{M}) \cong H_i(M \times [0, 1], \partial(M \times [0, 1]))$$

$$\cong H^{5-i}(M \times [0, 1]) \cong H^{5-i}(M) \cong H_{i-1}(M, \partial M).$$

In particular, we have $H_2(N_h, M) \cong H_1(M, \partial M) = 0$, since $M$ is simply connected and $\partial M$ is connected. Furthermore, under the isomorphism $H_3(N_h, M) \cong H_2(M, \partial M)$ given above, the boundary homomorphism $\partial : H_3(N_h, M) \to H_2(M)$ appearing in (2.1) is identified with the variation map $\Delta_h : H_2(M, \partial M) \to H_2(M)$. This completes the proof of Lemma 2.4. \hfill \square

Let us go back to the proof of Theorem 2.2. Let $h_0$ and $h_1 : M \to M$ be diffeomorphisms which are the identity on the boundary such that $\Delta_{h_0} = \Delta_{h_1}$. Set $h = h_0 \circ (h_1)^{-1}$. Then it is easy to show that $\Delta_h$ is the zero homomorphism (for example, see [10 §9]). Then by following the same argument as in [9 §2] and by replacing the Wang exact sequence for a bundle over $S^1$ with that of Lemma 2.4 we can construct a 6-dimensional manifold $W$ as in Lemma 2.4. Therefore, $h$ is pseudo-isotopic to the identity relative to boundary (see also the last paragraph of [10]). Thus $h_0$ and $h_1$ are pseudo-isotopic relative to boundary. Then by Quinn [15], they are stably isotopic relative to boundary. This completes the proof of Theorem 2.2. \hfill \square

Compare Theorem 2.2 with [10 Conjecture 9.6].

**Remark 2.5.** In the above situation, we can prove that $h_0 \sharp k(id)$ and $h_1 \sharp k(id)$ are pseudo-isotopic relative to boundary for some $k \geq 0$ also by using an argument based on the theory of open books on 5-dimensional manifolds [16, 17].

3. **Stable mapping class group and variational homomorphisms**

In this section, we define the stable mapping class group of a compact 4-manifold with boundary and give a result which describes it algebraically.
**Definition 3.1.** Let $M$ be a compact 4-manifold with boundary. A stable diffeomorphism of $M$ is a diffeomorphism of $M_k = M^k(S^2 	imes S^2)$ for some $k$. Two stable diffeomorphisms $h_0 : M_{k_0} \to M_{k_0}$ and $h_1 : M_{k_1} \to M_{k_1}$, which are the identity on the boundary, are said to be stably isotopic relative to boundary if $h_0 \circ k'_0(id) : M_{k_0 + k'_0} \to M_{k_0 + k'_0}$ and $h_1 \circ k'_1(id) : M_{k_1 + k'_1} \to M_{k_1 + k'_1}$ are isotopic relative to boundary for some $k'_0$ and $k'_1$ with $k_0 + k'_0 = k_1 + k'_1$. Finally, the set of all stable isotopy classes relative to boundary of stable diffeomorphisms of $M$ which are the identity on the boundary is called the stable mapping class group of $(M, \partial M)$ and is denoted by $\mathcal{SM}(M, \partial M)$. Note that if we denote by $\mathcal{M}(M, \partial M)$ the usual mapping class group relative to boundary, then we can naturally identify $\mathcal{SM}(M, \partial M)$ with the inductive limit

$$\lim_{k \to \infty} \mathcal{M}(M_k, \partial M_k).$$

This obviously forms a group with respect to the composition of maps.

Let $M$ be as above and let $h : M_k \to M_k$ be a stable diffeomorphism of $M$ which is the identity on the boundary. Let us denote the variation map of $h$ by $\Delta_h : H_2(M_k, \partial M_k) \to H_2(M_k)$. We also denote the induced map $h_* : H_2(M_k) \to H_2(M_k)$ by $\Lambda_h$. Since the intersection form

$$(3.1) \quad H_2(M_k) \times H_2(M_k, \partial M_k) \to \mathbb{Z}$$

of $M_k$ is unimodular, we may regard $H_2(M_k)$ and $H_2(M_k, \partial M_k)$ dual to each other. For a homomorphism $\rho$ involving these spaces, $\rho^*$ will denote its dual homomorphism. Let $j : M_k \to (M_k, \partial M_k)$ denote the inclusion map.

In order to give an algebraic description of the stable mapping class group, let us prepare some lemmas.

**Lemma 3.2.** We have the following:

1. $(j_\ast)^* = j_* : H_2(M_k) \to H_2(M_k, \partial M_k)$.
2. $\Lambda_h = id - \Delta_h \circ j_* : H_2(M_k) \to H_2(M_k)$.
3. $j_* = \Lambda_h^\ast \circ j_* \circ \Lambda_h : H_2(M_k) \to H_2(M_k)$.
4. $\Delta_h + \Delta_h^\ast = \Delta_h \circ j_* \circ \Delta_h^\ast : H_2(M_k, \partial M_k) \to H_2(M_k)$.
5. For two stable diffeomorphisms $h$ and $h' : M_k \to M_k$ which are the identity on the boundary, we have

$$\Delta_{h \circ h'} = \Delta_h + \Lambda_h \circ \Delta_{h'} : H_2(M_k, \partial M_k) \to H_2(M_k).$$

**Proof.** (1) This follows from the fact that $\alpha \cdot j_* \beta = \beta \cdot j_* \alpha$ for all $\alpha, \beta \in H_2(M_k)$, where “$\ast$” denotes the intersection form $B$

(2) For each $\alpha \in H_2(M_k)$, we have

$$(id - \Delta_h \circ j_\ast)(\alpha) = \alpha - (\alpha - h_* \alpha) = h_* \alpha = \Lambda_h \alpha.$$ 

Thus the result follows.

(3) This follows from the fact that $h_* : H_2(M_k) \to H_2(M_k)$ is an isometry of $(H_2(M_k), \cdot)$, where “$\ast$” denotes the intersection form of $M_k$ on $H_2(M_k)$.

(4) We have

$$\Delta_h + \Delta_h^\ast = \Delta_h \circ j_* \circ \Delta_h^\ast \quad \iff \quad (id - \Delta_h \circ j_\ast) \circ \Delta_h^\ast = -\Delta_h$$

$$\iff \quad \Lambda_h \circ \Delta_h^\ast = -\Delta_h$$

$$\iff \quad \Delta_h^\ast = -\Lambda_h^{-1} \circ \Delta_h,$$
where \( (3.2) \) follows from (2). This is equivalent to
\[
(3.4) \quad \Delta_h \beta \cdot \alpha = -(\Lambda_h^{-1} \circ \Delta_h \alpha) \cdot \beta
\]
for all \( \alpha, \beta \in H_2(M_k, \partial M_k) \). Let \( a \) and \( b \) be 2-cycles in \((M_k, \partial M_k)\) representing \( \alpha \) and \( \beta \), respectively. Then the right-hand side of the above equation is equal to
\[
-h^{-1}(a - ha) \cdot b = (a - h^{-1}a) \cdot b
\]
\[
= a \cdot b - h^{-1}a \cdot b
\]
\[
= b \cdot a - hb \cdot a
\]
\[
= (b - hb) \cdot a.
\]
Thus we have \( (3.4) \) and have proved the required equality.

(5) For every 2-cycle \( a \) of \((M_k, \partial M_k)\), we have
\[
-(h \circ h')a = a - ha + ha - h(h'a) = a - ha + h(a - h'a).
\]
Thus we have
\[
\Delta_h \circ h' = \Delta_h + \Lambda_h \circ \Delta_{h'}.
\]
This completes the proof. \( \square \)

**Definition 3.3.** Let \( M \) be a compact 4-manifold with boundary. A homomorphism \( \Delta : H_2(M, \partial M) \rightarrow H_2(M) \) is **variational** if \( \Delta + \Delta^* = \Delta \circ j_s \circ \Delta^* \). Let \( V(M, \partial M) \) denote the set of all variational homomorphisms.

**Lemma 3.4.** Let \( \Delta : H_2(M, \partial M) \rightarrow H_2(M) \) be a variational homomorphism. Then \( \Lambda = \mathrm{id} - \Delta \circ j_s \) is an isometry of the inner product space \((H_2(M), \cdot)\), where \( \cdot \) denotes the intersection form of \( M \) on \( H_2(M) \).

**Proof.** Since \( \Delta + \Delta^* = \Delta \circ j_s \circ \Delta^* \) holds by our assumption, we have \( j_s \circ (\Delta + \Delta^*) = j_s \circ \Delta \circ j_s \circ \Delta^* \). This is equivalent to the equality
\[
(\mathrm{id} - j_s \circ \Delta) \circ (\mathrm{id} - j_s \circ \Delta^*) = \mathrm{id} : H_2(M) \rightarrow H_2(M).
\]
Since \( H_2(M) \) is free, we see that \( \mathrm{id} - j_s \circ \Delta \) and \( \Lambda^* = \mathrm{id} - j_s \circ \Delta^* \) are isomorphisms which are inverses to each other. Thus \( \Lambda \) is an isomorphism and
\[
(\mathrm{id} - j_s \circ \Delta^*) \circ (\mathrm{id} - j_s \circ \Delta) = \mathrm{id}
\]
also holds. In particular, we have
\[
(\mathrm{id} - j_s \circ \Delta^*) \circ (\mathrm{id} - j_s \circ \Delta) \circ j_s = j_s,
\]
which is equivalent to \( \Lambda^* \circ j_s \circ \Lambda = j_s \). Thus \( \Lambda \) is an isometry. This completes the proof. \( \square \)

**Lemma 3.5.** The set \( V(M, \partial M) \) of all variational homomorphisms forms a group under the multiplication given by
\[
\Delta_1 \ast \Delta_2 = \Delta_1 + (\mathrm{id} - \Delta_1 \circ j_*) \circ \Delta_2,
\]
for \( \Delta_1, \Delta_2 \in V(M, \partial M) \).

**Proof.** Put \( V = V(M, \partial M) \) for simplicity. Let us first show that \( \Delta_1 \ast \Delta_2 \in V \). Putting \( \Lambda_i = \mathrm{id} - \Delta_i \circ j_*, \) \( i = 1, 2 \), we have
\[
(\Delta_1 \ast \Delta_2) + (\Delta_1 \ast \Delta_2)^* = (\Delta_1 + \Lambda_1 \circ \Delta_2) + (\Delta_1 + \Lambda_1 \circ \Delta_2)^*
\]
\[
= \Delta_1 + \Delta_1^* + \Lambda_1 \circ \Delta_2 + (\Lambda_1 \circ \Delta_2)^*.
\]
On the other hand, we have

$$(\Delta_1 \ast \Delta_2) \circ j_* \circ (\Delta_1 \ast \Delta_2)^*$$

$$= (\Delta_1 + \Lambda_1 \circ \Delta_2) \circ j_* \circ (\Delta_1 + \Lambda_1 \circ \Delta_2)^*$$

$$= \Delta_1 \circ j_* \circ \Delta_1^* + \Delta_1 \circ j_* \circ \Delta_2^* \circ \Lambda_1 + \Lambda_1 \circ \Delta_2 \circ j_* \circ \Delta_1^* + \Lambda_1 \circ \Delta_2 \circ j_* \circ \Delta_2^* \circ \Lambda_1^*$$

$$= (\Delta_1 + \Delta_1^*) + (\Delta_1 + \Delta_2) \circ j_* \circ \Delta_1^* + \Lambda_1 \circ \Delta_2 \circ j_* \circ \Delta_1^* + \Lambda_1 \circ (\Delta_2 + \Delta_2^*) \circ \Lambda_1^*$$

$$= (\Delta_1 + \Delta_1^*) + (\Delta_1 \circ j_* + \Lambda_1) \circ \Delta_2 \circ j_* \circ (\Delta_1^* + \Lambda_1^*)$$

$$= (\Delta_1 + \Delta_1^*) + \Lambda_1 \circ \Delta_2 \circ j_* \circ (\Delta_1^* + \Lambda_1^*)$$

Thus by (3.5), we see that $\Delta_1 \ast \Delta_2 \in \mathcal{V}$.

The associativity holds, since we have

$$\text{id} - (\Delta_1 \ast \Delta_2) \circ j_* = \text{id} - (\Delta_1 + (\text{id} - \Delta_1 \circ j_*) \circ \Delta_2) \circ j_*$$

(3.6)

and hence

$$(\Delta_1 \ast \Delta_2) \ast \Delta_3 = (\Delta_1 + \Lambda_1 \circ \Delta_2) \circ (\Delta_1 \circ \Delta_2) \circ \Delta_3$$

$$= \Delta_1 + \Lambda_1 \circ \Delta_2 \circ \Delta_3$$

$$= \Delta_1 \ast (\Delta_2 \ast \Delta_3).$$

It is obvious that the zero homomorphism is variational and is the identity element.

Finally, for $\Delta \in \mathcal{V}$, its inverse $\Delta^{-1}$ is given by

$$\Delta^{-1} = -\Lambda^{-1} \circ \Delta,$$

where $\Lambda = \text{id} - \Delta \circ j_*$ is an isometry of $(H_2(M), \cdot)$ by Lemma 3.4. This is seen as follows. We have

$$(-\Lambda^{-1} \circ \Delta) \circ j_* \circ (-\Lambda^{-1} \circ \Delta)^* = \Lambda^{-1} \circ \Delta \circ j_* \circ \Delta^* \circ (\Lambda^{-1})^*$$

$$= \Lambda^{-1} \circ (\Delta + \Delta^*) \circ (\Lambda^{-1})^*$$

$$= \Lambda^{-1} \circ \Delta \circ (\Lambda^{-1})^* \Lambda^{-1} \circ \Delta^* \circ (\Lambda^{-1})^*$$

$$= -\Delta^* \circ (\Lambda^{-1})^* - \Lambda^{-1} \circ \Delta$$

$$= (-\Lambda^{-1} \circ \Delta) + (-\Lambda^{-1} \circ \Delta)^*$$

by an argument similar to (3.6). Thus we have $\Delta^{-1} = -\Lambda^{-1} \circ \Delta \in \mathcal{V}$. Furthermore, since

$$\text{id} - (-\Lambda^{-1} \circ \Delta) \circ j_* = \Lambda^{-1} \circ (\Lambda + \Delta \circ j_*) = \Lambda^{-1},$$

we have

$$\Delta \ast (-\Lambda^{-1} \circ \Delta) = \Delta + \Lambda \circ (-\Lambda^{-1} \circ \Delta) = 0$$

and

$$(-\Lambda^{-1} \circ \Delta) \ast \Delta = -\Lambda^{-1} \circ \Delta + \Lambda^{-1} \circ \Delta = 0.$$

Thus $\mathcal{V}$ forms a group. This completes the proof.

**Definition 3.6.** A *stable variational homomorphism* of $M$ is a variational homomorphism $\Delta : H_2(M_k, \partial M_k) \to H_2(M_k)$ for some $k \geq 0$. Two stable variational homomorphisms $\Delta_0 : H_2(M_{k_0}, \partial M_{k_0}) \to H_2(M_{k_0})$ and $\Delta_1 : H_2(M_{k_1}, \partial M_{k_1}) \to H_2(M_{k_1})$ of $M$ are said to be *stably equivalent* if

$$\Delta_0 \oplus 0_{k_1} : H_2(M_{k_0} + k_1, \partial M_{k_0} + k_1) \cong H_2(M_{k_0}, \partial M_{k_0}) \oplus H_2(\mathbb{Z}^k_S(S^2 \times S^2))$$

$$\to H_2(M_{k_0} + k_1) \cong H_2(M_{k_0}) \oplus H_2(\mathbb{Z}^k_S(S^2 \times S^2)).$$
Theorem 3.7. If
\[ \text{This is a homomorphism of groups by Lemma 3.2(5).} \]

Proof. The well-definedness and the injectivity follow from Theorem 2.2.

Note that
\[ \text{where } \alpha \]

\[ \text{for some } k_0 \text{ and } k_1 \text{ with } k_0 + k_0' = k_1 + k_1', \text{ where} \]
\[ 0_{k'} : H_2(\mathbb{Z}^{k'}(S^2 \times S^2)) \rightarrow H_2(\mathbb{Z}^{k'}(S^2 \times S^2)) \]
stands for the zero map. The set of all equivalence classes of stable variational homomorphisms \( H_2(M_k, \partial M_k) \rightarrow H_2(M_k), k \geq 0, \) of \( M \) is called the stable variational group and is denoted by \( \mathcal{SV}(M, \partial M). \) It is not difficult to see that \( \mathcal{SV}(M, \partial M) \) naturally forms a group, which is nothing but the inductive limit
\[ \lim_{k \to \infty} \mathcal{V}(M_k, \partial M_k), \]
where we may naturally regard \( \mathcal{V}(M_k, \partial M_k) \subset \mathcal{V}(M_{k+1}, \partial M_{k+1}) \) for each \( k \geq 0. \)

We have a natural map
\[ \Theta : \mathcal{SM}(M, \partial M) \rightarrow \mathcal{SV}(M, \partial M), \]
which maps each class of a stable diffeomorphism to the class of its variation map. This is a homomorphism of groups by Lemma 3.2(5).

Theorem 3.7. If \( M \) is a smooth compact 1-connected 4-manifold with nonempty connected boundary, then the above correspondence \( \Theta \) gives an isomorphism of groups.

Proof. The well-definedness and the injectivity follow from Theorem 2.2.

Let \( \Delta : H_2(M_k, \partial M_k) \rightarrow H_2(M_k) \) be a stable variational homomorphism of \( M. \)

Note that
\[ \Lambda = \text{id} - \Delta \circ j_\ast : H_2(M_k) \rightarrow H_2(M_k) \]
is an isometry of \( (H_2(M_k), \cdot) \) by Lemma 3.4.

The following lemma has been proved implicitly in the proof of Lemma 3.2(see (5.3)).

Lemma 3.8. \( \Delta \beta \cdot \alpha = -\langle \Lambda^{-1} \circ \Delta \alpha \rangle \cdot \beta \) for all \( \alpha, \beta \in H_2(M_k, \partial M_k). \)

Let \( V = M^0 \cup \text{id} (-M^1) \) with \( M^0 = M^1 = M_k \) be the double of \( M_k, \) which is a smooth closed 1-connected 4-manifold. Furthermore, let \( \delta : H_2(M_k, \partial M_k) \rightarrow H_2(V) \) be the doubling homomorphism, which is given by
\[ \delta([a]) = [i_0a - i_1a], \]
where \( a \) is an arbitrary 2-cycle of \( (M_k, \partial M_k) \) and \( i_0 : M^0 \rightarrow V \) and \( i_1 : M^1 \rightarrow V \) are the inclusion maps. Then put
\[ J' = \text{im}(\delta + i_1 \ast \circ \Delta : H_2(M_k, \partial M_k) \rightarrow H_2(V)). \]

Furthermore, let \( G(-\Lambda) \) denote the subgroup of \( H_2(M^0) \oplus H_2(M^1) \) consisting of the elements of the form \( (\alpha, -\Lambda \alpha), \alpha \in H_2(M^0), \) where we regard \( \Lambda \) as an isomorphism from \( H_2(M^0) \) to \( H_2(M^1). \) Let \( \iota : H_2(M^0) \oplus H_2(M^1) \rightarrow H_2(V) \) be the natural homomorphism induced by the inclusions. Then we have the following.

Lemma 3.9. \( \iota G(-\Lambda) \subset J'. \)
Proof. For every $\alpha \in H_2(M_k)$, we have
\[
(\delta + i_{1*} \circ \Delta)(j_* \alpha) = (i_{0*} \alpha - i_{1*} \alpha) + i_{1*} \circ \Delta \circ j_* \alpha \\
= (i_{0*} \alpha - i_{1*} \alpha) + i_{1*}(\alpha - \Lambda \alpha) \\
= i_{0*} \alpha - i_{1*} \circ \Lambda \alpha.
\]
This shows our required inclusion. \hfill \Box

Lemma 3.10. The subgroup $J'$ of $H_2(V)$ is isotropic.

Proof. For every $\alpha, \beta \in H_2(M_k, \partial M_k)$, we have
\[
(\delta + i_{1*} \circ \Delta)(\alpha) \cdot (\delta + i_{1*} \circ \Delta)(\beta) \\
= \delta \alpha \cdot \delta \beta + \delta \alpha \cdot (i_{1*} \circ \Delta \beta) + (i_{1*} \circ \Delta \alpha) \cdot \delta \beta + (i_{1*} \circ \Delta \alpha) \cdot (i_{1*} \circ \Delta \beta) \\
= \Delta \beta \cdot \alpha + \Delta \alpha \cdot \beta - \Delta \alpha \cdot (j_* \circ \Delta \beta) \\
= (\Delta \beta \cdot \alpha + \Delta^* \beta \cdot \alpha) - (\Delta^* \circ j_* \circ \Delta \beta) \cdot \alpha = 0,
\]
since $\delta \alpha \cdot \delta \beta = 0$ and $\Delta$ is variational. This completes the proof. \hfill \Box

Consider the Mayer-Vietoris exact sequence for the pair $(M^0, M^1)$:
\[
0 \longrightarrow H_2(\partial M_k) \longrightarrow H_2(M^0) \oplus H_2(M^1) \xrightarrow{\iota} H_2(V) \xrightarrow{\partial'} H_1(\partial M_k) \longrightarrow 0.
\]

Lemma 3.11. We have $\partial' J' = H_1(\partial M_k)$.

Proof. For every $\alpha \in H_2(M_k, \partial M_k)$, we have
\[
\partial' \circ (\delta + i_{1*} \circ \Delta) \alpha = \partial' \circ \delta \alpha = \partial \alpha,
\]
where $\partial : H_2(M_k, \partial M_k) \rightarrow H_1(\partial M_k)$ is the boundary homomorphism in the exact sequence of the pair $(M_k, \partial M_k)$:
\[
0 \longrightarrow H_2(\partial M_k) \longrightarrow H_2(M_k) \rightarrow H_2(M_k, \partial M_k) \xrightarrow{\partial} H_1(\partial M_k) \longrightarrow 0.
\]
Since $\partial$ is surjective, we have the conclusion. \hfill \Box

Let $J$ be a maximal isotropic subgroup of $H_2(V)$ containing $J'$. Then by [8 (4.2)] (see also [BR]), there exists a smooth $h$-cobordism $W$ relative to boundary between $M^0$ and $M^1$ such that
\[
\ker(\kappa_* : H_2(V) \rightarrow H_2(W)) = J,
\]
where $\kappa : V \rightarrow W$ is the inclusion map. Let $\eta : M^0 \rightarrow M^1$ be the homotopy equivalence relative to boundary induced by the $h$-cobordism $W$. We can define the variation map $\Delta_\eta : H_2(M^0, \partial M^0) \rightarrow H_2(M^1)$ of $\eta$ as before.

Lemma 3.12. The variation map $\Delta_\eta$ coincides with $\Delta$.

Proof. Since $J' \subset \ker \kappa_*$, we have
\[
-\kappa_* \circ \delta = \kappa_* \circ i_{1*} \circ \Delta : H_2(M^0, \partial M^0) \rightarrow H_2(W).
\]
Let $a$ be an arbitrary 2-cycle of $(M^0, \partial M^0)$. Then we have
\[
\kappa_* \circ i_{1*} \circ \Delta_\eta[a] = \kappa_* \circ i_{1*}([a - \eta a]) \\
= [\kappa \circ i_1 a - \kappa \circ i_0 a] \\
= \kappa_*(-\delta[a]) \\
= \kappa_* \circ i_{1*} \circ \Delta[a].
\]
Since $\kappa_\ast \circ i_1 \ast : H_2(M^1) \rightarrow H_2(V)$ is an isomorphism, we have $\Delta_0 = \Delta$. This completes the proof. \hfill \Box

Now taking the connected sum along cobordisms of the smooth $h$-cobordism $W$ with the trivial cobordism $(t^k S^2 \times S^2) \times [0, 1]$ for some $k'$, we see that $\Delta$ is realized stably by a stable diffeomorphism of $M$ \cite{11}, \cite{14}. Hence the correspondence $\Theta$ is surjective. This completes the proof of Theorem 3.7. \hfill \Box

Remark 3.13. Using an argument similar to the above together with the topological $h$-cobordism theorem of Freedman \cite{5}, we can also obtain some results about the topological mapping class group of topological 4-manifolds with boundary without stabilization. More precisely, let $M$ be a compact 1-connected topological 4-manifold with nonempty connected boundary. Let $\mathcal{M}^{\text{TOP}}(M, \partial M)$ denote the group of topological isotopy classes relative to boundary of the homeomorphisms of $M$ which are the identity on the boundary. Then we have the natural map

$$\Theta^{\text{TOP}} : \mathcal{M}^{\text{TOP}}(M, \partial M) \rightarrow \mathcal{V}(M, \partial M)$$

which maps each isotopy class of a homeomorphism to its variation map. Then the argument in the proof of Theorem 3.7 shows that $\Theta^{\text{TOP}}$ is surjective. We do not know if it is injective or not.

4. Relation to stable isometry group

In this section, we study the relationship between the stable variational group and the stable isometry group of a 4-manifold with boundary.

Definition 4.1. Let $M$ be a compact 4-manifold with boundary. We denote by $\mathcal{I}(M)$ the isometry group of the inner product space $(H_2(M), \langle \cdot, \cdot \rangle)$, where $\langle \cdot, \cdot \rangle$ denotes the intersection form. A stable isometry of $M$ is an isometry of $(H_2(M_k), \langle \cdot, \cdot \rangle)$ for some $k$. Two stable isometries $\Lambda_0 : H_2(M_{k_0}) \rightarrow H_2(M_{k_0})$ and $\Lambda_1 : H_2(M_{k_1}) \rightarrow H_2(M_{k_1})$ of $M$ are said to be stably equivalent if the isometry $\Lambda_0 \oplus \text{id}$ of $(H_2(M_{k_0+k_0}'), \langle \cdot, \cdot \rangle) = (H_2(M_{k_0}) \oplus H_2(t^{k_0} S^2 \times S^2), \langle \cdot, \cdot \rangle)$ and the isometry $\Lambda_1 \oplus \text{id}$ of $(H_2(M_{k_1+k_1}'), \langle \cdot, \cdot \rangle) = (H_2(M_{k_1}) \oplus H_2(t^{k_1} S^2 \times S^2), \langle \cdot, \cdot \rangle)$ coincide with each other for some $k_0$ and $k_1$ with $k_0+k_0' = k_1+k_1'$. The set of all equivalence classes of stable isometries of $M$ is called the stable isometry group of $M$ and is denoted by $\mathcal{SI}(M)$, which can naturally be identified with the inductive limit

$$\lim_{k \rightarrow \infty} \mathcal{I}(M_k).$$

This obviously forms a group with respect to the composition of isometries.

Let $M$ be a 1-connected 4-manifold with nonempty connected boundary $\partial M = K$. For each variational homomorphism $\Delta \in \mathcal{V}(M, \partial M)$, the endomorphism $\Lambda = \text{id} - \Delta \circ j_\ast$ is an isometry of $(H_2(M), \langle \cdot, \cdot \rangle)$ by Lemma 3.4. Let us define

$$\Xi : \mathcal{V}(M, \partial M) \rightarrow \mathcal{I}(M)$$

by $\Xi \Delta = \Lambda$. By \cite{17}, $\Xi$ is a homomorphism of groups.

Let us denote by $\wedge^2 H_1(K)^\ast$ the set of all skew-symmetric bilinear forms $H_1(K) \times H_1(K) \rightarrow \mathbb{Z}$. Note that this naturally forms an additive group, which is finitely generated and free abelian. Note that an element $\kappa \in \wedge^2 H_1(K)^\ast$ can also be
regarded as a homomorphism $H_1(K) \to \text{Hom}(H_1(K), \mathbb{Z}) \cong H^1(K) \cong H_2(K)$. For such an element $\kappa$, define $\kappa : H_2(M, \partial M) \to H_2(M)$ by the composition

$$H_2(M, \partial M) \xrightarrow{\partial} H_1(K) \xrightarrow{\kappa} H_2(K) \xrightarrow{\iota_*} H_2(M),$$

where $\partial : H_2(M, \partial M) \to H_1(K)$ is the boundary homomorphism and $\iota : K \to M$ is the inclusion. Then we can easily check that $\kappa$ is a variational homomorphism and that the map $S : \wedge^2 H_1(K)^* \to \mathcal{V}(M, \partial M)$ defined by $Sk = \kappa$ is an injective homomorphism.

The main result of this section is the following.

**Proposition 4.2.** For a compact 1-connected 4-manifold $M$ with nonempty connected boundary $\partial M = K$, the sequence

$$0 \longrightarrow \wedge^2 H_1(K)^* \xrightarrow{S} \mathcal{V}(M, \partial M) \xrightarrow{\Xi} \mathcal{I}(M)$$

is exact.

**Proof.** We have already observed that $S$ is injective.

It is easy to check that $\text{im} S \subset \ker \Xi$. Suppose that $\Delta$ is an element of $\ker \Xi$. Thus $\Xi \Delta = \text{id} - \Delta \circ j_*$ is the identity of $H_2(M)$ and hence $\Delta = 0$ on $\text{im} j_* = \ker \partial$. Thus we may regard $\Delta$ as a homomorphism

$$H_2(M, \partial M)/\ker \partial \cong H_1(K) \to H_2(M).$$

On the other hand, since $\Delta$ is variational, we have $\Delta + \Delta^* = \Delta \circ j_* \circ \Delta^* = 0$. Hence, we have $0 = \Delta \circ j_* + \Delta^* \circ j_* = \Delta^* \circ j_*$, which implies that $j_* \circ \Delta = 0$. Thus $\text{im} \Delta \subset \ker j_* = H_2(K)$. Hence $\Delta$ can be regarded as a homomorphism $\kappa : H_1(K) \to H_2(K)$. Now it is easy to check that $\kappa \in \wedge^2 H_1(K)^*$ and $\Delta = Sk$.

This completes the proof. \qed

We can characterize the image of $\Xi$ as follows. Let us first take a basis

$$\{\alpha_1, \alpha_2, \ldots, \alpha_u, \alpha_{u+1}, \ldots, \alpha_{u+v}\}$$

of $H_2(M)$ over the integers, where $u = \text{rank } H_2(K)$, $u + v = \text{rank } H_2(M)$, and

$$\{\alpha_1, \alpha_2, \ldots, \alpha_u\}$$

is a basis of $\iota_* H_2(K)$. This is possible, since $\iota_* H_2(K)$ is a direct summand of $H_2(M)$. For $H_2(M, \partial M)$, we take the dual basis

$$\{\alpha_1^*, \alpha_2^*, \ldots, \alpha_u^*, \alpha_{u+1}^*, \ldots, \alpha_{u+v}^*\}$$

such that the intersection number in $M$ satisfies $\alpha_k \cdot \alpha_l^* = \delta_{kl}$, where

$$\delta_{kl} = \begin{cases} 1, & k = l, \\ 0, & k \neq l. \end{cases}$$

Let

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix}$$

be the matrix representation of a homomorphism $\Delta : H_2(M, \partial M) \to H_2(M)$ with respect to the above basis, where $A, B, C$ and $D$ are $u \times u$, $u \times v$, $v \times u$ and $v \times v$ integral matrices, respectively. Furthermore, we see easily that the matrix representation of $j_*$ with respect to the above basis must be of the form

$$\bar{Q} = \begin{pmatrix} 0 & 0 \\ 0 & Q \end{pmatrix}$$
for some nonsingular \(v \times v\) integral matrix \(Q\). Then it is easy to see that \(\Delta\) is variational if and only if

\[
D + tD = DQ^tD, \quad A + tA = BQ^tB, \quad B + tC = BQ^tD.
\]

Thus, an isometry \(\Lambda \in \mathcal{I}(M)\) is in the image of \(\Xi\) if and only if, with respect to the above basis, \(\Lambda\) is represented by a matrix of the form

\[
\begin{pmatrix}
v & -BQ \\
v & E_v - DQ
\end{pmatrix}
\]

such that

\[
D + tD = DQ^tD, \quad A + tA = BQ^tB, \quad B + tC = BQ^tD
\]

for some integral matrices \(A, B, C\) and \(D\), where \(E_w\) denotes the \(w \times w\) unit matrix.

If the diagonal entries of \(Q\) are even, or if \(H_2(K) = 0\), then we can show that this condition is equivalent to that the following diagram is commutative:

\[
\begin{array}{ccccccc}
0 & \to & H_2(K) & \xrightarrow{i} & H_2(M) & \xrightarrow{j^*} & H_2(M, \partial M) & \xrightarrow{\partial} & H_1(K) & \to & 0 \\
\downarrow{\text{id}} & & \downarrow{\Lambda} & & \downarrow{\Lambda^*} & & \downarrow{\text{id}} & & \\
0 & \to & H_2(K) & \xrightarrow{i} & H_2(M) & \xrightarrow{j^*} & H_2(M, \partial M) & \xrightarrow{\partial} & H_1(K) & \to & 0.
\end{array}
\]

In this case, we have the exact sequence

\[
0 \to \Lambda^2 H_1(K)^* \xrightarrow{S} \mathcal{V}(M, \partial M) \xrightarrow{\Xi} \mathcal{I}(M) \xrightarrow{\partial} A_Q(K) \to 0,
\]

where \(\partial\) and \(A_Q(K)\) are a homomorphism and a group as defined in [3, §1].

If some diagonal entries of \(Q\) are not even and \(H_2(K) \neq 0\), then the commutativity of the diagram is still necessary, but it is not sufficient in general.

In fact, using Boyer’s obstruction class \(\theta\), we can show the following.

**Proposition 4.3.** An isometry \(\Lambda \in \mathcal{I}(M)\) is in the image of \(\Xi : \mathcal{V}(M, \partial M) \to \mathcal{I}(M)\) if and only if \(\partial \Lambda = \text{id} \in A_Q(K)\) and Boyer’s obstruction \(\theta(\text{id}, \Lambda) \in I_1^1(K)\) vanishes, where \(I_1^1(K) = \text{im}(H^1(K) \to H^1(K; \mathbb{Z}_2))\).

**Proof.** Suppose \(\partial \Lambda = \text{id} \neq 0\). Then by Boyer [3, §1], there exists a homeomorphism \(h : M \to M\) such that \(h|_{\partial M} = \text{id}\) and \(h_* = \Lambda\). Let \(\Delta = \Delta_h \in \mathcal{V}(M, \partial M)\) be the variation map of \(h\). Then it is easy to see that \(\Xi \Delta = \Lambda\).

Conversely, if \(\Lambda = \Xi \Delta\) for some \(\Delta\), then we have already seen that \(\partial \Lambda = \text{id}\). Furthermore, by Remark [3.13] there exists a homeomorphism \(h : M \to M\) such that \(h|_{\partial M} = \text{id}\) and \(\Delta_h = \Delta\). Hence by Boyer [3, §1], the obstruction \(\theta(\text{id}, \Lambda_h)\) vanishes, where \(\Lambda_h = h_*\). Since \(\Lambda_h = \Xi \Delta_h = \Lambda\) by Lemma [3.2(2)], we have \(\theta(\text{id}, \Lambda) = 0\). This completes the proof.

Note that when the diagonal entries of \(Q\) are even or \(H_2(K) = 0\), the obstruction \(\theta(\text{id}, \Lambda)\) always vanishes (see [3, (0.8) Proposition]).

The above proposition can also be proved purely algebraically by using the above-mentioned characterization of the image of \(\Xi\) in terms of matrices, together with the definition of the obstruction \(\theta\).

All the above results hold stably as well. More precisely, we can naturally define the homomorphisms

\[
\mathcal{S} : \wedge^2 H_1(K)^* \to \mathcal{S}\mathcal{V}(M, \partial M), \quad \mathcal{S} \Xi : \mathcal{S}\mathcal{V}(M, \partial M) \to \mathcal{S}\mathcal{I}(M),
\]
and the sequence

\[ 0 \longrightarrow \wedge^2 H_1(K)^* \xrightarrow{\varphi_2} H_2(M) \xrightarrow{j_*} H_2(M, \partial M) \xrightarrow{\partial} H_1(K) \longrightarrow 0 \]

is exact. The characterization of the image of \( \Xi \) holds similarly for \( S\Xi \) as well.

5. **Boundary-free diffeomorphisms**

In this section, we study the stable mapping class group of boundary-free diffeomorphisms of compact 4-manifolds whose boundaries are certain spherical 3-manifolds.

**Definition 5.1.** Let \( M \) be a compact 4-manifold with boundary. Two stable diffeomorphisms \( h_0 : M_{k_0} \rightarrow M_{k_0} \) and \( h_1 : M_{k_1} \rightarrow M_{k_1} \) of \( M \), which may not necessarily be the identity on the boundary, are said to be *stably isotopic* if the diffeomorphisms \( h_0 \sharp_0^k(id) : M_{k_0+k_0} \rightarrow M_{k_0+k_0} \) and \( h_1 \sharp_1^k(id) : M_{k_1+k_1} \rightarrow M_{k_1+k_1} \) are smoothly isotopic for some \( k_0 \) and \( k_1 \) with \( k_0 + k_0' = k_1 + k_1' \). Note that the isotopy should leave the boundary invariant as a set, but can move points on the boundary. The set of all stable isotopy classes of stable diffeomorphisms of \( M \) is called the *stable mapping class group of boundary free diffeomorphisms* of \( M \) and is denoted by \( SM(M) \). This obviously forms a group with respect to the composition of maps.

Let \( \Lambda : H_2(M) \rightarrow H_2(M) \) be an isometry of a compact 4-manifold \( M \) with boundary \( K \). Then we have the commutative diagram

\[
\begin{array}{cccccc}
0 & \rightarrow & H_2(K) & \xrightarrow{\iota_*} & H_2(M) & \xrightarrow{j_*} & H_2(M, \partial M) & \xrightarrow{\partial} & H_1(K) & \rightarrow & 0 \\
\varphi_2 & & \downarrow \Lambda & & \downarrow j_* & & \downarrow \Lambda^* & & \downarrow \varphi_1 & & \\
0 & \rightarrow & H_2(K) & \xrightarrow{\iota_*} & H_2(M) & \xrightarrow{j_*} & H_2(M, \partial M) & \xrightarrow{\partial} & H_1(K) & \rightarrow & 0
\end{array}
\]

for some isomorphisms \( \varphi_1 \) and \( \varphi_2 \), where \( \iota : \partial M \rightarrow M \) and \( j : M \rightarrow (M, \partial M) \) denote the inclusions. Let \( A(K) \) denote the group of automorphisms of \( H_*(K) \), where an automorphism is required to preserve the torsion linking pairing \( T_1(K) \times T_1(K) \rightarrow \mathbb{Q}/\mathbb{Z} \) on the torsion subgroup \( T_1(K) \) of \( H_1(K) \) together with the intersection pairing \( H_1(K) \times H_2(K) \rightarrow \mathbb{Z} \) (for details, see [3 §1]). Note that the isomorphism of \( H_*(K) \) determined by \( (\varphi_1, \varphi_2) \) in (5.1) is an automorphism and that the map

\[ \partial : \mathcal{I}(M) \rightarrow A(K) \]

defined by \( \partial \Lambda = (\varphi_1, \varphi_2) \) is a homomorphism.

Furthermore, let \( H_+(K) \) denote the subgroup of \( A(K) \) consisting of those automorphisms which are realized by an orientation preserving homeomorphism of \( K \).

Set \( T^0(M) = \partial^{-1}(H_+(K)) \), which is a subgroup of \( \mathcal{I}(M) \). It is easy to observe that we naturally have

\[ T^0(M) \subset T^0(M_1) \subset \cdots \subset T^0(M_k) \subset T^0(M_{k+1}) \subset \cdots \]

Thus we can define the inductive limit

\[ S\mathcal{I}^0(M) = \lim_{k \to \infty} T^0(M_k), \]

which is also a group.
Note that if $H_1(K) = 0$, then we have $ST^0(M) = ST(M)$. Note also that if $h : M_k \rightarrow M_k$ is an orientation preserving stable diffeomorphism of $M$, then $h_* : H_2(M_k) \rightarrow H_2(M_k)$ lies in $ST^0(M)$.

The main result of this section is the following.

**Theorem 5.2.** Let $M$ be a smooth compact 1-connected 4-manifold with boundary $\partial M$ homeomorphic to a lens space $L(p, q)$ ($p \geq 2$), the 3-sphere $S^3$, or the Poincaré homology 3-sphere $\Sigma(2,3,5)$. Then the correspondence

$$\Theta^h : SM(M) \rightarrow ST^0(M)$$

which maps each class of a stable diffeomorphism to the class of its induced isometry of the second homology group gives an isomorphism of groups.

**Proof.** Suppose that $h : M_k \rightarrow M_k$ is a stable diffeomorphism of $M$ such that $\Theta^h h$ is the identity. Then the automorphism $(h|_{\partial M})_*$ of $H_*(\partial M)$ must be the identity by a commutative diagram similar to (5.1). Then by results of [1], [2], [6], and [7] together with our assumption on the boundary, we see that $h|_{\partial M}$ is smoothly isotopic to the identity. Thus, by extending the isotopy to the whole of $M$ using the collar neighborhood, we may assume that $h|_{\partial M}$ is the identity. On the other hand, since $H_3(\partial M)$ is finite, the homomorphism $\Xi : V(M_k, \partial M_k) \rightarrow I(M_k)$ is injective by Proposition (1.2). Hence the variation map of $h$ must be the zero homomorphism. Thus by Theorem (2.2), $h$ is stably isotopic to the identity diffeomorphism (relative to boundary). Thus the homomorphism $\Theta^h$ is injective.

Let $\Lambda : H_2(M_k) \rightarrow H_2(M_k)$ be a stable isometry of $M$ such that $\Lambda \in I^0(M_k)$. Then by the definition of $I^0(M_k)$, there exists an orientation preserving homeomorphism $f : \partial M_k \rightarrow \partial M_k$ such that $\partial \Lambda = f_*$. We may assume that $f$ is a diffeomorphism (see [12]). Then by [3] (0.8 Proposition) together with the fact that $H_4(\partial M; Q) = 0$, we see that Boyer’s obstruction $\theta(f, \Lambda)$ vanishes, which implies that there exists a homeomorphism $\tilde{f} : M_k \rightarrow M_k$ such that $\tilde{f}_* = \Lambda$ and $\tilde{f}|_{\partial M} = f$. Then by using the stable $h$-cobordism theorem [11], [14] together with an argument as in [3] [4] for constructing a smooth $h$-cobordism, we can show that there exists a diffeomorphism $\tilde{f}'$ of $M_{k+k'}$ for some $k' \geq 0$ such that $\tilde{f}'|_{\partial M} = \tilde{f}|_{\partial M}$ and $\tilde{f}'$ and $\tilde{f}_*$ are stably equivalent. Hence $\Theta^h$ is surjective. This completes the proof.

**Remark 5.3.** For the lens space $L(p, q)$, $p \geq 2$, the structure of $H_*(L(p, q))$ has been determined. In fact, according to [2], $H_+(L(p, q))$ coincides with

1. $\{\text{id}\}$, if $p = 2$,
2. $\{\pm \text{id}, \pm q\}$, if $q^2 \equiv 1 \pmod{p}$ and $q \neq \pm 1 \pmod{p}$,
3. $\{\pm \text{id}\}$, otherwise,

where $\pm q$ stands for the multiplication by $\pm q$. Thus, if $\partial M$ is diffeomorphic to $L(p, q)$ which satisfies (1) or (3), then $ST^0(M)$ coincides with $ST(M)$.

**References**


License or copyright restrictions may apply to redistribution; see http://www.ams.org/journal-terms-of-use


Faculty of Mathematics, Kyushu University, Hakozaki, Fukuoka 812-8581, Japan

E-mail address: saeki@math.kyushu-u.ac.jp